Targeted Tile Drainage for Agronomic and Environmental Efficiencies

Final Report

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Executive Summary

Temporary and seasonal wetlands have been shown to provide many ecological benefits in natural landscapes but are less beneficial and can be problematic in land under commercial crop production. Landowners and producers have used tile drainage to manage excess water from temporary and seasonal wetlands, and have demonstrated agronomic, environmental, and economic benefits to this practice. However, there has been little formal research in Saskatchewan to address this topic.

The SaskFSA have commissioned a study with the objective to identify and quantify soil and crop production benefits of using tile drainage to manage excess water associated with temporary or seasonal wetlands in a prairie pothole landscape.

Tile drainage was installed on three separate fields in fall 2020. The tile was installed using a targeted design, with the purpose of consolidating of several shallow and seasonal wetlands within each field. A study was designed to monitor changes in the soil and in crop productivity in the landscape in and around the managed wetlands, for three years following the tile installation (2021-2023). The soil characteristics that were assessed included soil organic matter, residual phosphorus and nitrate-N, and soluble salts. Yield maps were used to assess changes in crop productivity. Water samples were also collected in spring of 2022 to serve as a baseline for water quality indicators.

Notable changes in crop productivity were observed over the three years of the study. Previously uncropped areas and marginal areas had significant increases in productivity three years after installation of tile drainage, and this indicates a large economic benefit to tile drainage in pothole landscapes. There also visually appears to be a trend in all three fields towards decreasing soluble salts in all soil depths from the initial year to the third year.

Soil organic matter and residual phosphorus did not change significantly in the landscape surrounding the managed wetlands over the three years of the study. The changes in residual nitrate-N was likely attributable to other crop management factors. Soils characteristics are slow to change and may need to be monitored over several years to assess the long-term impacts of tile drainage installation. It is also possible that the installation of tile drainage in fact has negligible effects on soil characteristics, even in the long-term, especially when combined with responsible crop production practices such as variable rate nutrient management. The recommendation would be to monitor yield data and fertilizer mapping annually, along with monitoring soil characteristics, conducting soil testing again in two to three years using the GPS soil sampling sites. A more formal water sampling protocol and schedule would also provide better insight on the movement of nutrients in areas influenced by tile drainage in comparison to unmanaged wetlands.

Project Objective

To identify and quantify soil and crop production benefits of using targeted tile drainage to manage excess water associated with temporary or seasonal wetlands in a prairie pothole landscape.

Project Rationale

Temporary wetlands (Class 1 and Class II) typically have fairly rapid water seepage, but surface water that usually lingers for a few weeks after spring snowmelt and for several days after heavy rainstorms at other times of the year. Seasonal wetlands (Class III) usually dry up by midsummer. These types of wetlands provide many ecological benefits in natural landscapes but can be problematic in land under commercial crop production.

When temporary or seasonal wetlands are located in land under crop production, they can cause production inefficiencies such as delayed field operations due to waterlogged soil, slowed field operations and overlap of product applications due to equipment having to operate non-linearly over the landscape. Crop productivity is affected by excess water, salinity, and compaction issues in the areas surrounding the wetlands.

Landowners and producers use both surface and tile drainage to manage and remove excess water from temporary and seasonal wetlands. While surface drainage is predominant in Saskatchewan, tile drainage has become more common in recent years.

Tile drainage effectively lowers the water table, so crop productivity is increased in areas that used to be waterlogged. Nutrient uptake may also potentially be increased as crop productivity increases, and also because roots are able to penetrate deeper in the soil. The lower water table also provides temporary storage space for excess water from snowmelt or rain events, resulting in more soil holding capacity and less overland flow of water and nutrients.

There are several designs that are used when installing tile drainage, depending on the objective of drainage and the hydrology of the landscape. Different types of tile drainage systems include parallel (grid or systematic), herringbone and network (or targeted) tile drainage. Targeted tile drainage design is appropriate in hummocky (or pothole) landscapes, where only a minor proportion of the land is affected by excess water.

In consideration of the production benefits offered, the SaskFSA would like to demonstrate that tile drainage can be part of good land stewardship, providing environmental benefits, such as increased nutrient uptake, decreased overland flow, and more efficient use of inputs.

Methodology

The study was conducted in the R.M. of Kellross No. 247. Tile drainage was installed by the landowners on three separate fields in fall 2020, prior to the initiation of the study. The tile was installed using a targeted design, with the purpose of consolidating several wetlands of varying sizes and permanence, all shallow and seasonal, within each field.

Study Design

The study was designed to monitor changes in the soil and in crop productivity in the landscape in and around the managed wetlands, in the years following the tile installation.

The edges of the managed wetlands, or areas that were previously uncropped, were delineated using geo-rectified aerial photography that was taken in the fall of 2020 (Figures 1 – 3).

Four separate zones were defined in the areas in and around the managed wetlands:

1) Zone 1 is the interior of the managed wetland, or the previously uncropped area.
2) Zone 2 comprises a 60-foot width around the outside edge of the managed wetland, or the first seeding pass using the cooperating operation's 60-foot seeding implement and represents the marginal cropland and potential saline area.
3) Zone 3 is the second pass of the seeding implement around the wetland, so comprises the area between 60 and 120 ft from the edge of the wetland and represents the potential overlap and compaction zone.
4) Zone 4 is between 120 and 180 ft from the edge of the wetland and represents the control or where we would expect average crop productivity, unaffected by the managed wetland.

Table 1. Quick reference table summarizing the features of the managed wetland zones examined in the study.

Zone 1	Wetland; Previously uncropped (drained wetland)
Zone 2	Marginal Cropland; Saline (60 feet)
Zone 3	Potential Overlap and Compaction (60-120 feet)
Zone 4	Normal or Average Crop Productivity (120-180 feet)

Different sizes, locations, and permanence of wetlands would be expected to respond differently to tile drainage over time based on their hydrology, specifically, the amount and direction of flow of water in the soil and overland in the surrounding landscape. Thus, soil and crop productivity in each of the four zones was examined on three or four separate managed wetlands of varying sizes in each of the three fields and monitored for three years following the tile installation.

Data collection

Four sets of soil sample sites were identified in each of the four zones around the different managed wetlands in each field. Nitrogen fertilizer was applied at a variable rate (VR) in each of the three fields. Thus, using the VR prescription map, sets of soil sample sites from each of the managed wetland zones were grouped in the same VR management zone to control for the effect of applied fertilizer rate. Different sets of soil sample sites were located in different VR management zones across the various wetlands (Figures 1 – 3).

Soil samples were collected at each sample site before seeding in the spring of 2021, 2022, and 2023. A dutch auger was used to remove 3 soil cores at each sample site, separated by depth from 0 to 6 inches, 6 to 12 inches, and 12 to 24 inches. The 3 cores were combined into a single sample for each depth. The samples were dried, ground, and submitted to a third-party lab for a complete analysis of soil properties and nutrients. Non-mobile soil characteristics were only measured for the topsoil depth.

After harvest was completed, yield maps were obtained from the cooperating grower. SMS (Spatial Management System, Ag Leader Technology Inc.) and QGIS (www.qgis.org) were utilized to extract and clean the raw data and determine the yield within each of the four managed wetland zones in each field.

Water sampling was conducted in the spring of 2022. In each field, grab samples were collected from a tile drain outlet, a consolidation water body, and an unmanaged wetland (comparative to the tiled wetland) at the start and end of spring runoff (April 20 and May 5). Samples were not collected from the tile drain outlet on the second sample date because outlets were below the water level. Samples were kept cool and submitted to a third-party lab within 48 hours for general chemical analysis and dissolved nutrients.

Statistical Analysis

Data were analyzed with the R statistical program (R Core Team 2022), using the *lme4* package for fitting mixed-effects models, the *lmerTest* package for assessing model fit and treatment differences, and the *emmeans* package for means separation. To assess differential changes in soil characteristics and crop productivity in each field in the zones surrounding the managed wetlands, mixed effects models were fitted for organic matter (OM) and P (Olsen) in the topsoil, for nitrate-N and soluble salts at all three soil depths, and for yield. Yields were standardized within fields each year using Min-Max scaling (Standardized yield = Yield – (minimum yield * maximum yield) – minimum yield) to allow the comparison of different crop types with different yield potentials. The three fields were analyzed separately because of inherent differences in soil type, crop type, cropping history, and landscape topography which would be expected to influence the effect of tile drainage. Fixed effects were zone, year, and their interaction. For factors measured at different soil depths, fixed effects also included depth and all two- and three-way interactions. Random effects for the soil variables was replicate within year, replicates consisting of the grouped sets of four soil sample sites. Random effects for yield was wetland within year. Estimated marginal means were determined and means were separated using multiple pairwise comparisons with the Tukey method for P-value adjustment and the Satterthwaite method for determining degrees of freedom. Treatments were considered significantly different at $P<0.05$. Water sample data was not statistically analysed because there was no replication within fields.

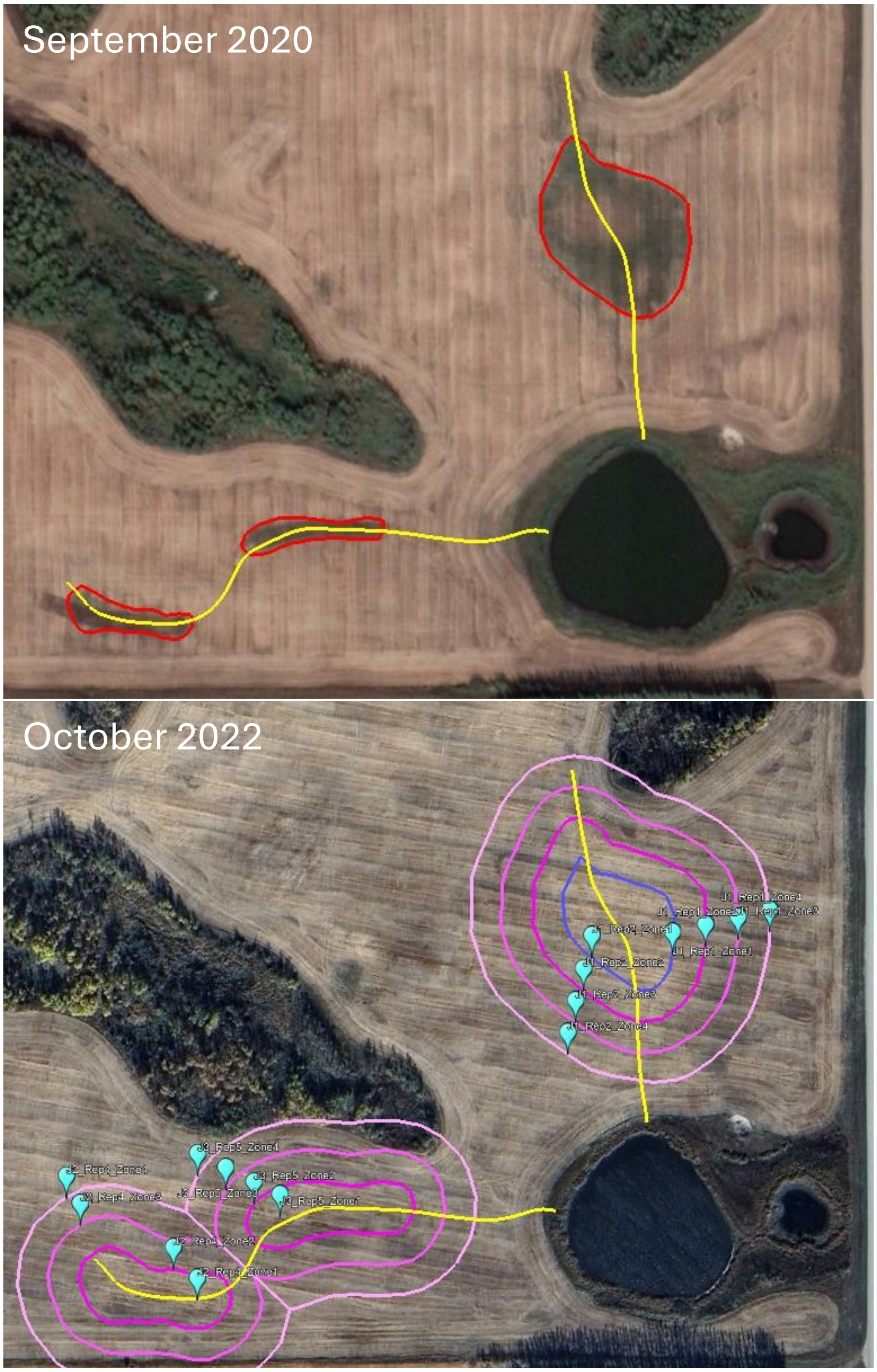


Figure 1. Aerial imagery of Field 1 in September 2020, prior to installation of tile drainage (top), and in October 2022, two growing seasons after tile installation (bottom). Location of installed tile is shown in yellow in both images. The edge of the managed wetlands and previously uncropped areas are delineated in red in the top image. On the bottom image, coloured lines run through the centre of each of the four zones; Zone 1 is not visible on the smaller two managed wetlands as the wetland was less than 60 ft wide. Point markers indicate the location of each of the four sets of soil sample sites.

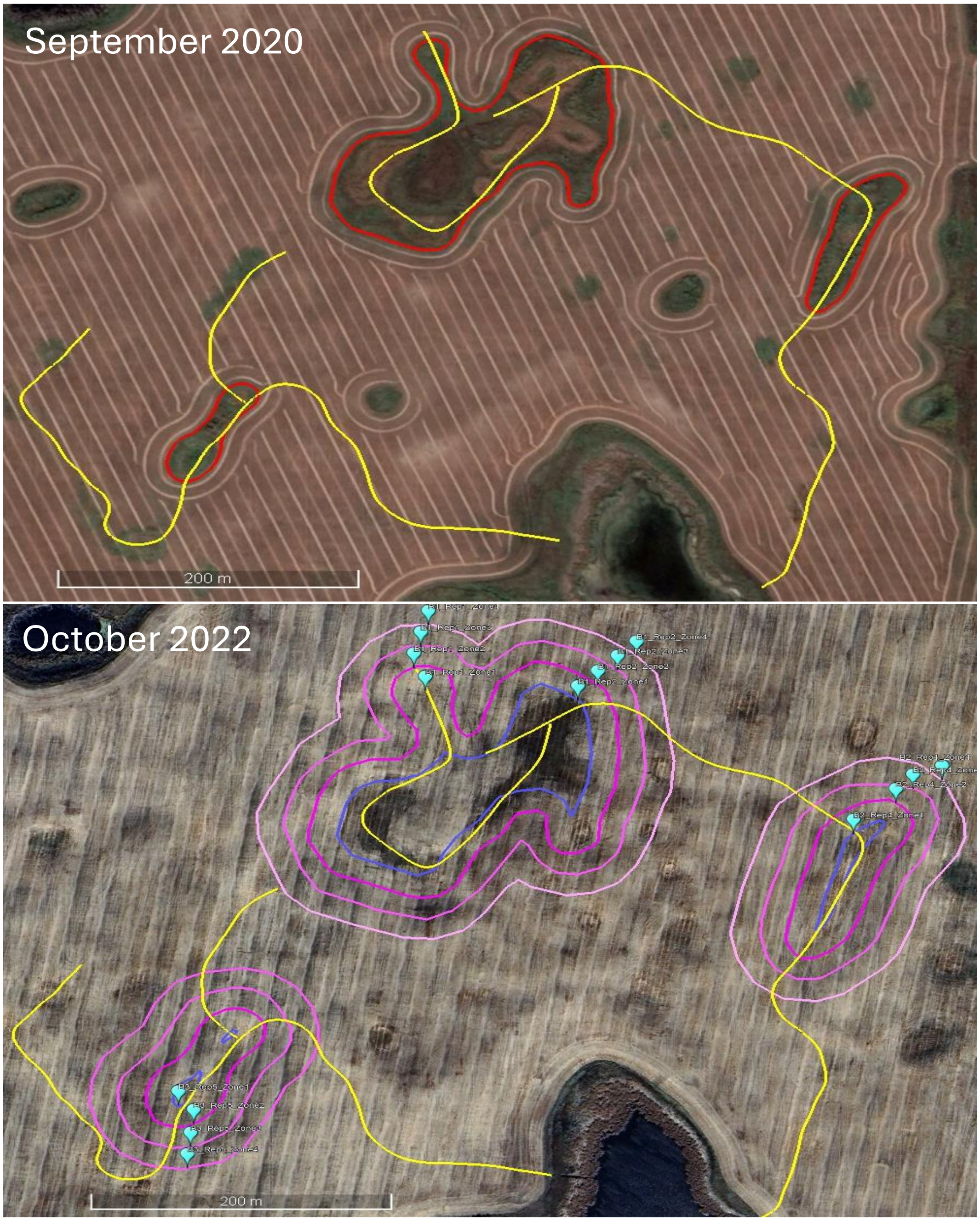


Figure 2. Aerial imagery of Field 2 in September 2020, prior to installation of tile drainage (top), and in October 2022, two growing seasons after tile installation (bottom). Location of installed tile is shown in yellow in both images. The edge of the managed wetlands and previously uncropped areas are delineated in red in the top image. On the bottom image, coloured lines run through the centre of each of the four zones. Point markers indicate the location of each of the four sets of soil sample sites.

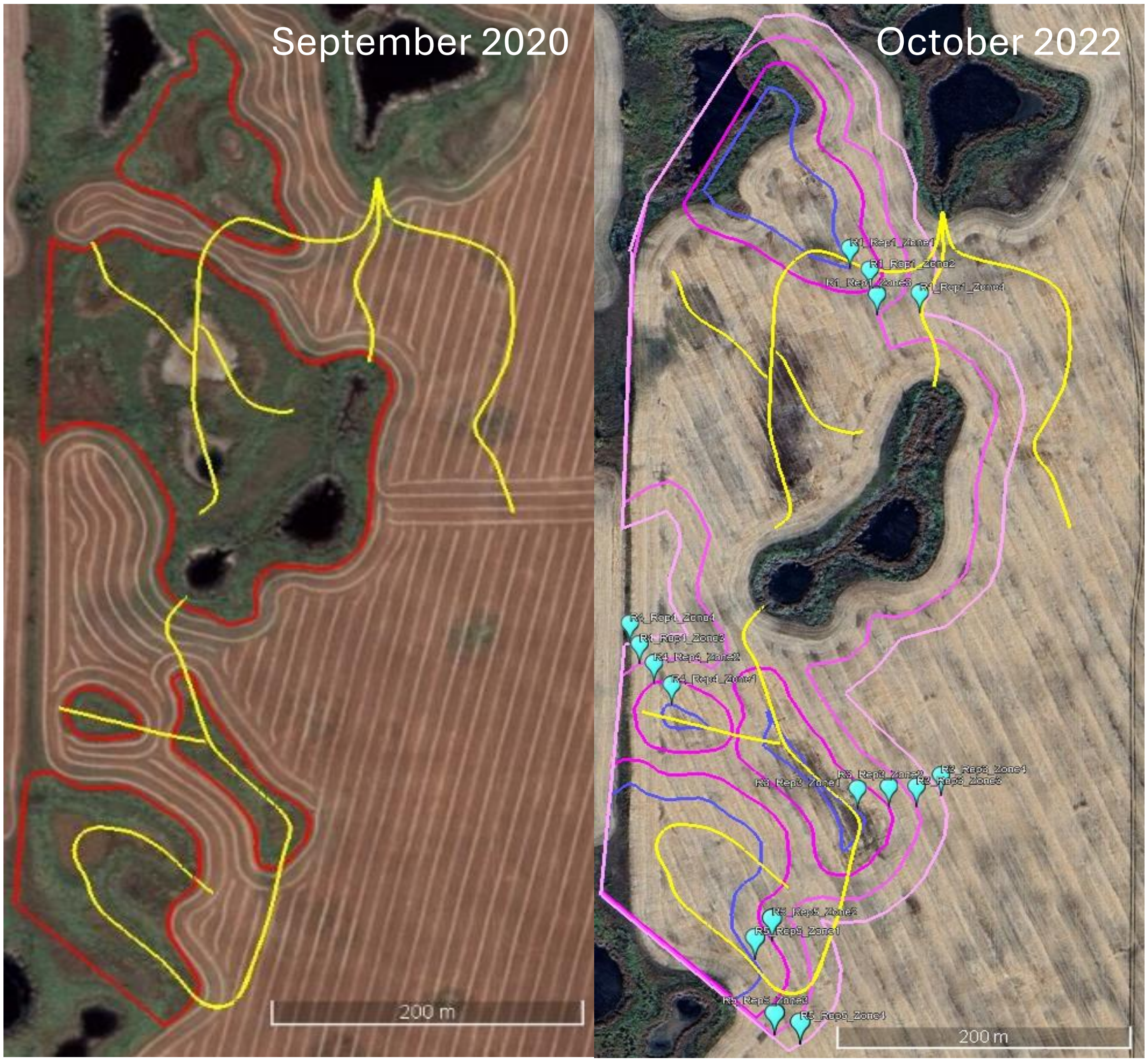


Figure 3. Aerial imagery of Field 3 in September 2020, prior to installation of tile drainage (left), and in October 2022, two growing seasons after tile installation (right). Location of installed tile is shown in yellow in both images. The edge of the managed wetlands and previously uncropped areas are delineated in red in the first image. On the second image, coloured lines run through the centre of each of the four zones. Point markers indicate the location of each of the four sets of soil sample sites.

Results and Discussion

For each response variable (OM, nitrate-N, P, salts, and yield), the data are shown separately by year regardless of whether the results differed significantly, to show the change in measured values year over year. P-values indicating statistically significant differences between zones, years, soil depths, and their interactions are shown in tables, and mean values across all sample sites and wetlands within fields, are shown in the figures. If there was a significant difference between zones, letters will be shown in the figures to indicate how the zones differed – zones showing the same letter are not significantly different from each other. Error bars in the figures show the standard error, which indicates how variable the measured values were for that particular factor. A greater standard error makes it more difficult to detect statistically significant differences.

Soil Organic Matter

Soil organic matter (OM) is a soil quality factor that is non-mobile in the soil profile. Soil OM is an indicator of soil carbon storage and is relevant in water management research as wetlands have been shown to be carbon sinks.

Soil OM would be expected to stay fairly stable with the installation of tile drainage. Soil OM matter is affected by productivity of the crop or of natural vegetation, by additions of residue, and by the rate of decomposition and/or mineralization. With the installation of tile drainage, Zone 1 should transition from natural vegetation or no vegetation to an annual crop. A potential improvement in soil conditions in Zones 2 and 3 may increase productivity and residue in these zones. In contrast, a reduction in waterlogging could increase decomposition and soil mineralization in Zones 1, 2, and 3. Productivity, residue, decomposition and mineralization are not expected to change in Zone 4.

In Field 1, there was no significant difference in OM between the zones in any of the three years, while in Fields 2 and 3, OM was significantly higher in Zone 1 than the other three zones over the 3 years of the study (Table 2, Figure 4). A higher level of OM in Zone 1 would likely be a result of long-term waterlogging in this zone, leading to low rates of decomposition and mineralization. In each of the three fields, the Zone by Year interaction was not significant, indicating that the OM level in each zone remained stable over the three years of the study. In Fields 2 and 3, a potential reduction in OM could be seen in Zone 1 over time as decomposition and soil mineralization would be expected to increase with reduced waterlogging from the addition of tile drainage.

Table 2. P-values of statistical tests examining the difference in soil organic matter (OM) between managed wetland zones and years in each of the three fields. A P-value <0.05 indicates a statistically significant difference and is bolded for emphasis.

	Field 1	**Field 2**	**Field 3**
Zone	0.440	**<0.001**	**<0.001**
Year	0.848	0.630	0.803
Zone:Year	0.902	0.951	0.946

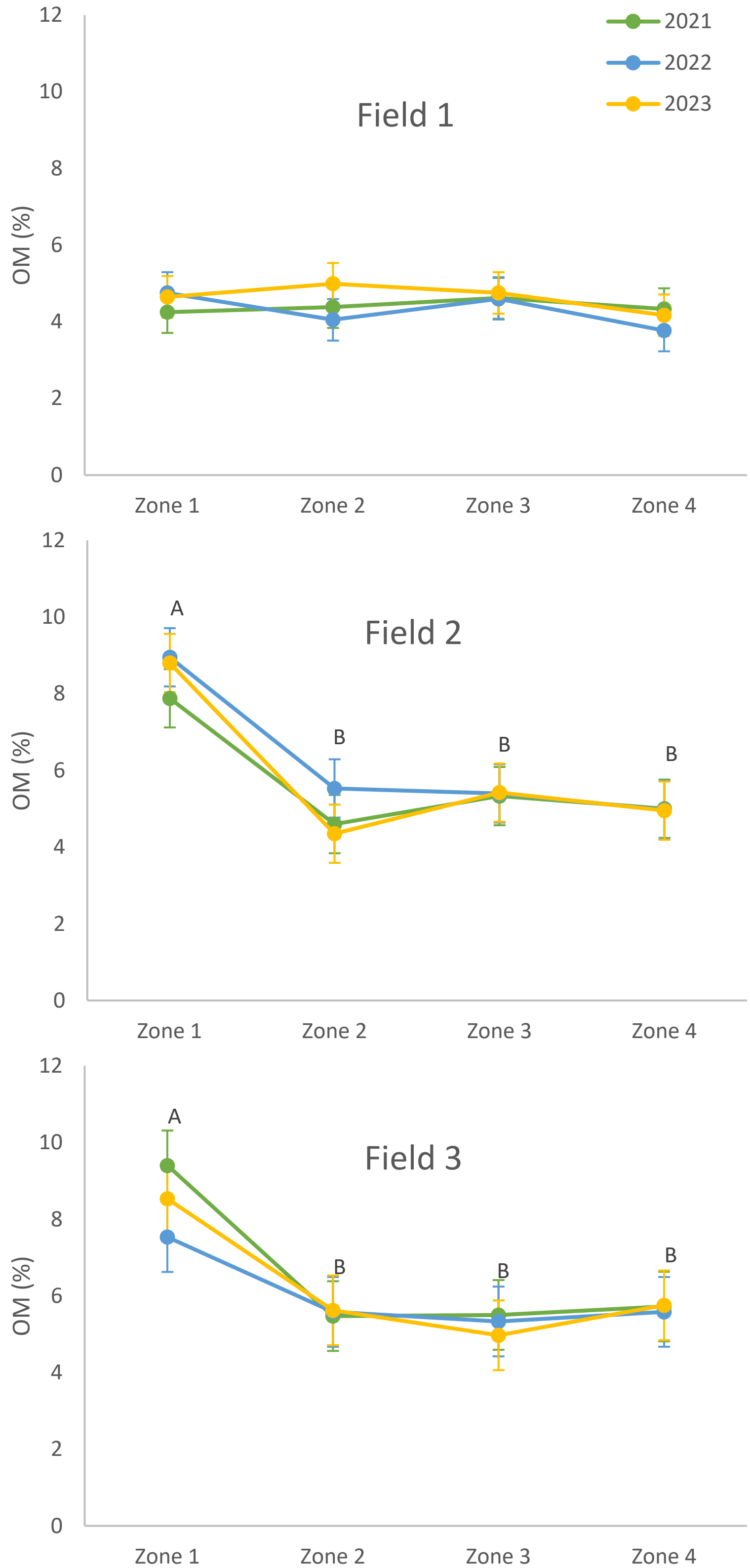


Figure 4. The difference in soil organic matter (OM) in the four managed wetland zones over the three years of the study. Zones with the same letter are not significantly different (upper case indicates across all years). Letters are not shown for non-significant tests.

Residual Phosphorus

Phosphorus (P) is considered non-mobile in the soil profile but can move overland with the flow of water and soil particles. We expect less overland water movement with the installation of tile drainage. Thus, it was hypothesized that soil P would potentially have been accumulating in the wetland, or Zone 1, due to overland flow of water, and would initially be high in this zone. Soil P may potentially also have been accumulating in Zones 2 and 3 due to applications of fertilizer, along with reduced crop productivity in these zones. Uptake of the nutrient could potentially increase with crop establishment in Zone 1, and with increased productivity in Zones 2 and 3.

In Fields 1 and 2, the level of P differed significantly between zones, but there was no difference in P between zones in Field 3 over the 3 years of the study (Table 3). In Fields 1 and 2, P was significantly higher in Zone 1 than in the other zones, other than Zone 3 in Field 2, which had elevated levels of P compared to Zones 2 and 4 (Figure 5). The Zone by Year interaction was not significant, indicating that the P level within zones did not change across the three years of the study.

Table 3. P-values of statistical tests examining the difference in residual phosphorus (P) between managed wetland zones and years in each of the three fields. A P-value <0.05 indicates a statistically significant difference and is bolded for emphasis.

	Field 1	**Field 2**	**Field 3**
Zone	**0.001**	**0.002**	0.071
Year	0.331	0.540	0.941
Zone:Year	0.946	0.501	0.891

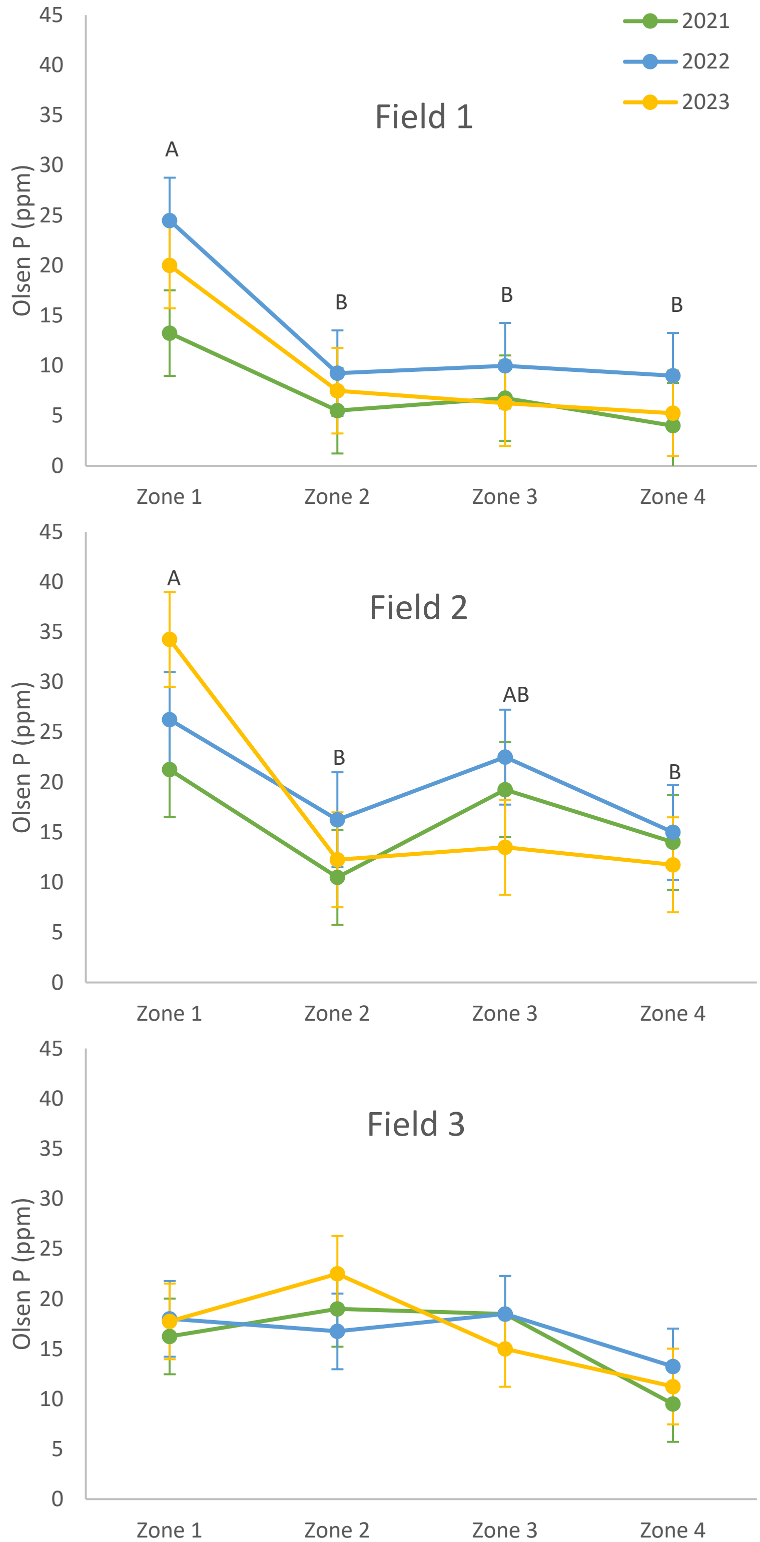


Figure 5. The difference in residual phosphorus (P) in the four managed wetland zones over the three years of the study. Zones with the same letter are not significantly different (upper case indicates across all years). Letters are not shown for non-significant tests. Measurements are on a 6” depth soil sample, thus lbs/ac = ppm x2.

Residual N

Nitrate-N is mobile in the soil profile and so is measured at different depths. Thus, we are examining changes in nitrate-N from year to year in each of the zones as well as changes in the different depths, indicating movement in the soil profile, after installation of tile drainage.

Crop establishment in Zone 1 and increased crop productivity in Zones 2 and 3 could improve uptake of residual and applied N. N cycling would also be affected by a reduction in waterlogging, and nitrate-N could be more prone to leaching with increased downward movement of water with the installation of tile drainage.

There were several significant interactions between zone, depth, and year in all three fields, but the three-way interaction was not significant in any field (
Table 4). The difference between years was evident with nitrate-N. Anhydrous ammonia (NH_3) was applied to all three fields in the fall of 2021, after a dry growing season with low yield potential. In all three fields, nitrate-N levels across soil depth layers and zones overall were elevated compared to the previous year, and then returned to the lower levels in the following year. Further, a significant Depth by Year interaction would indicate that the overall level of nitrate-N in separate soil profile depths, across all zones, differed from year to year. The Depth by Year interaction was significant in all three fields (
Table 4). In all three fields, the effect was such that the difference between soil profile depths became significant in 2022 because of elevated nitrate-N levels, where they weren't significant in 2021 or 2023. Interestingly, in Field 3, nitrate-N became elevated in the deeper soil depths rather than the topsoil layer, which could indicate leaching. The significant variation in nitrate-N among soil depth layers from year to year, separate from the differences between the zones, would not likely be related to the installation of tile drainage and so is not shown in the figures.

However, a significant Zone by Year interaction indicates that the difference in nitrate-N between zones changed from year to year, and could be a result of tile drainage, but could also have occurred naturally regardless of tile drainage. The Zone by Year interaction was significant in Field 1, and was such that there was initially no significant difference in nitrate-N between zones in 2021, then a significantly elevated level of nitrate-N in Zones 1 and 2 in 2022, and back to no significant difference between zones in 2023 (Figure 6). The Zone by Year interaction was not significant in Fields 2 and 3, indicating that there was no significant difference in nitrate-N between zones, regardless of soil profile depth, in any of the three years of the study.

Table 4. P-values of statistical tests examining the difference in nitrate-N between managed wetland zones, soil profile depths, and years in each of the three fields. A P-value <0.05 indicates a statistically significant difference and is bolded for emphasis.

	Field 1	**Field 2**	**Field 3**
Zone	**0.001**	0.274	0.181
Depth	**<0.001**	**<0.001**	0.143
Year	**<0.001**	**<0.001**	**<0.001**
Zone:Depth	0.929	0.959	0.382
Zone:Year	**<0.001**	0.897	0.240
Depth:Year	**0.001**	**<0.001**	**<0.001**
Zone:Depth:Year	0.439	0.612	0.628

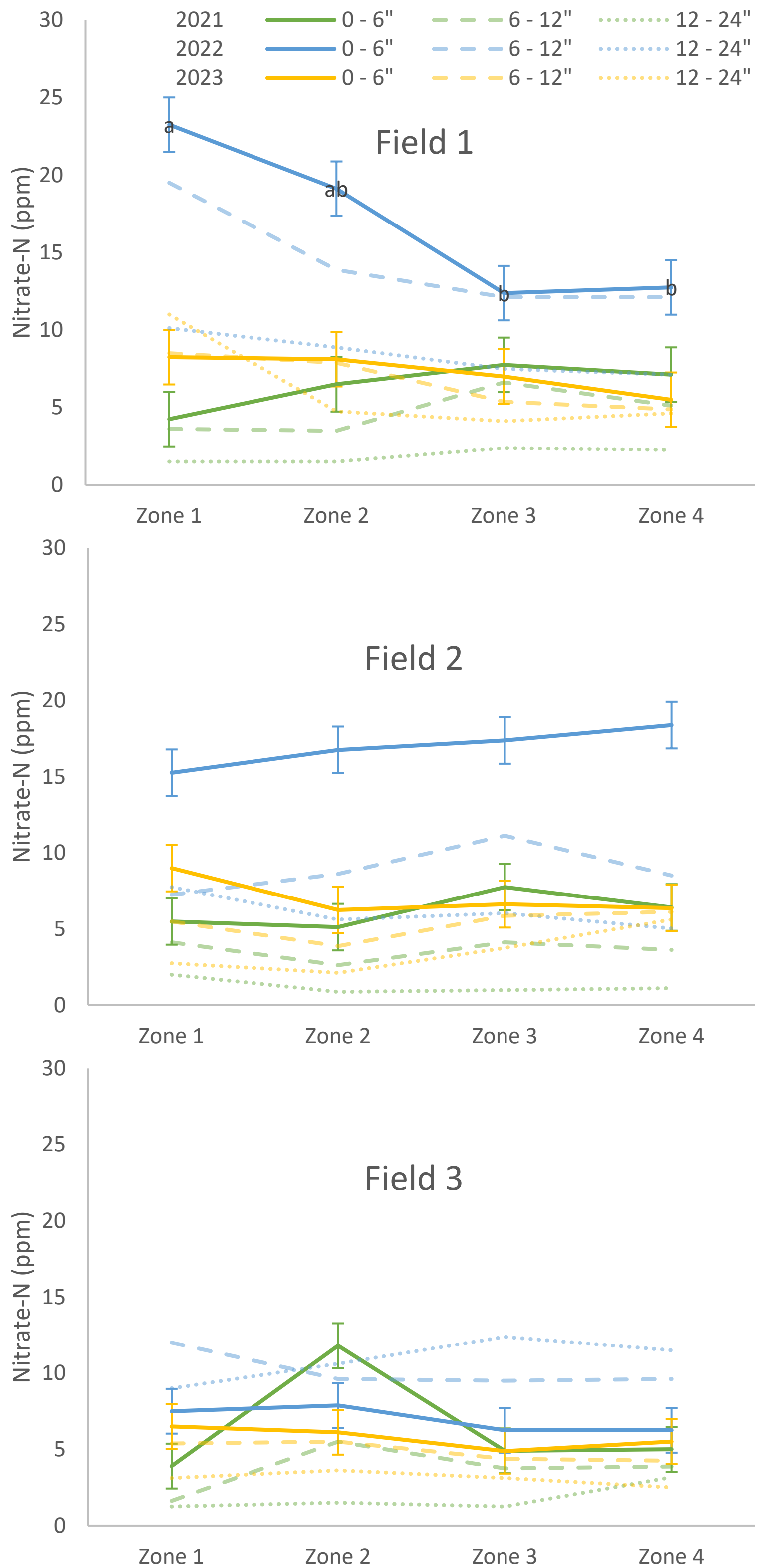


Figure 6. The difference in nitrate-N at three different soil profile depths in the four managed wetland zones over the three years of the study. Zones with the same letter are not significantly different (lower case indicates within a single year). Letters are not shown for non-significant tests. To convert ppm to lbs/ac, multiply by 2 for each 6" depth.

Soluble Salts

Soluble salts are a measure of salinity and are measured as electrical conductivity. Like nitrates, salts move with water in the soil profile so are also measured at different depths. However, unlike nitrate-N, the movement and accumulation of salts is not tied to nutrient application and crop uptake.

There was a significant difference between zones in all three fields, and no significant interactions, which means that the difference between zones was consistent across soil depths and did not change over the three years of the study (Table 5). In Field 1, salinity was significantly higher in Zone 2 than in all three of the other zones (Figure 7). Field 3 was similar but the salt level was higher and so the difference between zones was more pronounced; Zone 1 was also significantly higher in soluble salts than Zones 3 and 4. In Field 2, salts were significantly higher in Zone 3 than all other zones and was lowest in Zone 1. Salts would be expected to be initially higher in Zones 2 or 3, due to the effect of water evaporation and water movement on the edges of the wetland. Salts would be expected to decrease in these Zones with the installation of tile drainage, however this would be dependent on precipitation and may happen slowly over time.

There was also a significant difference in salts at different depths, across zones and years, in Field 2, but the Depth by Year interaction was not significant which means that the differences between depths did not change from year to year (Table 5, Figure 7). However, there visually appears to be a trend in all three fields towards decreasing soluble salts in all soil depths from the initial year to the third year.

Table 5. P-values of statistical tests examining the difference in soluble salts between managed wetland zones, soil profile depths, and years in each of the three fields. A P-value <0.05 indicates a statistically significant difference and is bolded for emphasis.

	Field 1	Field 2	Field 3
Zone	**<0.001**	**<0.001**	**<0.001**
Depth	0.054	**0.023**	0.075
Year	0.945	0.515	0.971
Zone:Depth	0.833	0.561	0.956
Zone:Year	0.661	0.335	0.494
Depth:Year	0.242	0.964	0.851
Zone:Depth:Year	0.999	0.999	0.813

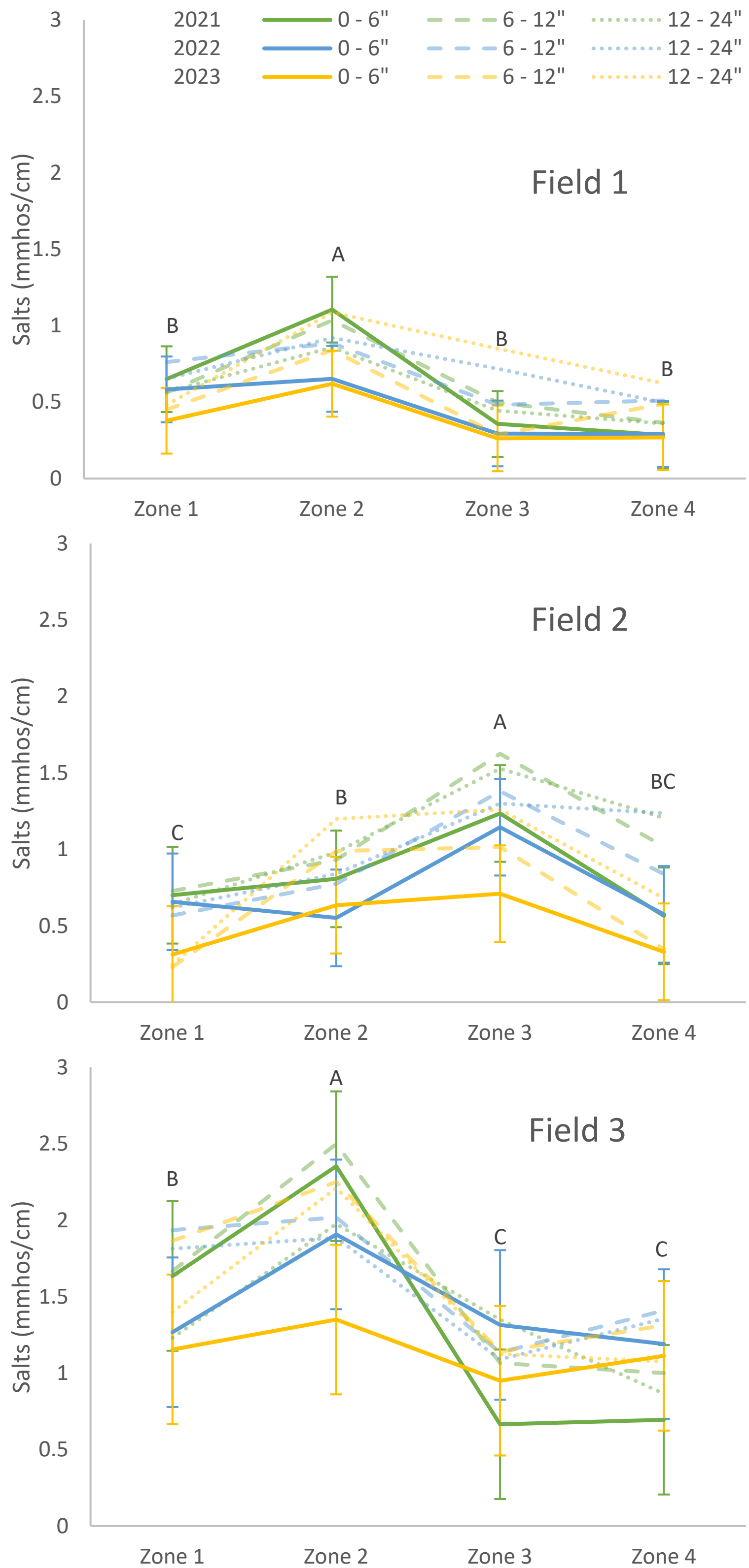


Figure 7. The difference in soluble salts at three different soil profile depths in the four managed wetland zones over the three years of the study. Zones with the same letter are not significantly different (upper case indicates across all years).

Yield

Yields are affected by soil OM, nutrients, salinity, and excess or deficit of water, all of which can be influenced by the presence of wetlands and/or installation of tile drainage. It is difficult to compare yields directly from year to year as different crops are grown with different yield potentials and tolerance to the effects of the variables mentioned above. Yields were standardized within fields and years to help address this issue. Yield maps also help to visually assess the variation in yield in the zones surrounding the managed wetlands in each of the fields (Figure 8, Figure 9, Figure 10). Regardless of the crop and yield potential, lighter points indicate lower yields and darker points indicate higher yields for each field in each year.

The Zone by Year interaction was significant for all three fields (Table 6), which means that the difference in yield between zones varied from year to year. In Field 1, yield was significantly different in all four zones and decreased gradually from the highest yield in Zone 1 to the lowest yield in Zone 4, in the first two years (Figure 11). The trend was similar in 2023, but yield was proportionally higher in Zone 1, and similar in Zones 3 and 4. Fields 2 and 3 had similar responses to tile drainage. In 2021, yield was lowest in Zone 1 and similar in the other three zones. In 2022, yield was highest in Zone 4 and similar in the other three zones. In 2023, yield was significantly higher in Zone 1 and yield decreased gradually from Zone 1 to Zone 4. Standardized yields are shown in the figures for comparison, but actual yields can be referenced in Table 7.

Yield response to tile drainage will be highly dependent on the amount of precipitation received during the growing season, and how the crops grown respond to an excess or a deficit of water. It is difficult to interpret the results for these reasons, but notably, it is apparent that there was a significant increase in productivity in Zone 1 and to a lesser extent in Zone 2, in the third year of the study, in all three fields, regardless of the crop grown. However, further monitoring will be important to assess whether this increased productivity will be sustained, how long it might be sustained, whether it eventually stabilizes, and how the increased productivity will affect soil characteristics in the long term.

Table 6. P-values of statistical tests examining the difference in standardized yield between managed wetland zones and years in each of the three fields. A P-value <0.05 indicates a statistically significant difference and is bolded for emphasis.

	Field 1	**Field 2**	**Field 3**
Zone	**<0.001**	**<0.001**	**<0.001**
Year	**0.031**	0.126	**0.013**
Zone:Year	**<0.001**	**<0.001**	**<0.001**

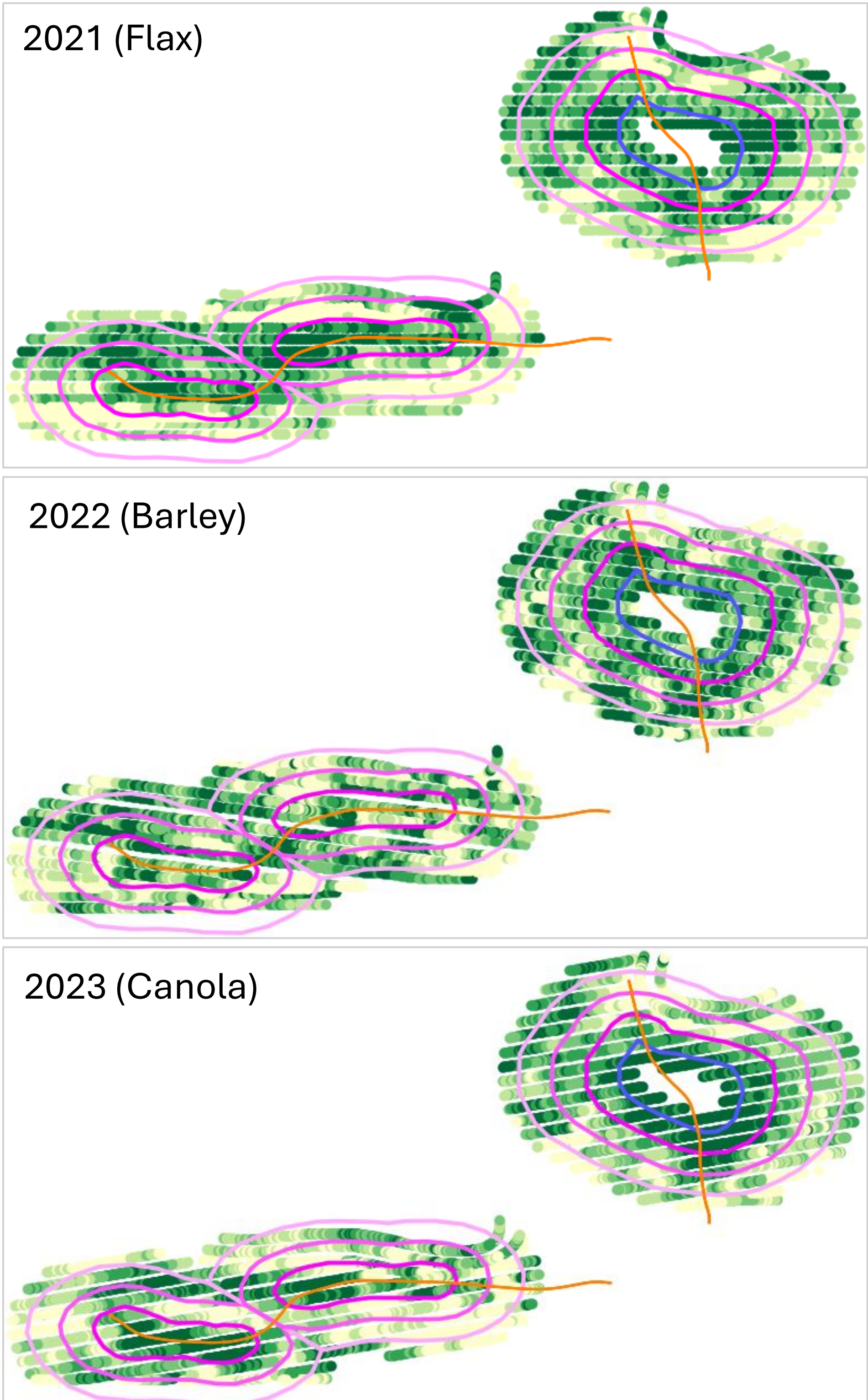


Figure 8. Yield maps showing variation in yield in the zones surrounding the managed wetlands in Field 1 in all three years of the study. Lighter points indicate lower yields and darker points indicate higher yields and were determined for each crop and field separately. The orange lines represent the targeted tile drainage through the wetland.

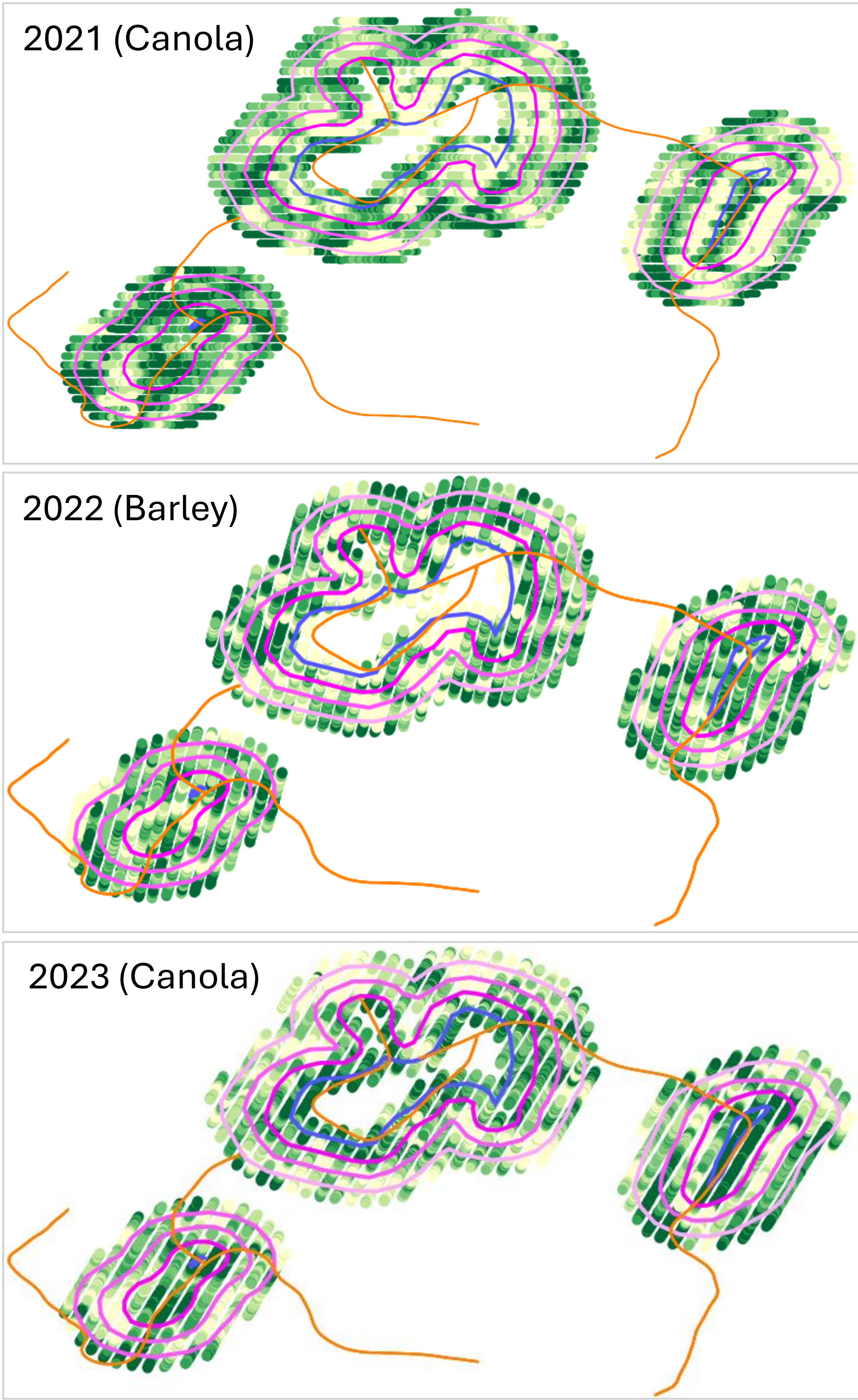


Figure 9. Yield maps showing variation in yield in the zones surrounding the managed wetlands in Field 2 in all three years of the study. Lighter points indicate lower yields and darker points indicate higher yields and were determined for each crop and field separately. The orange lines represent the targeted tile drainage through the wetland.

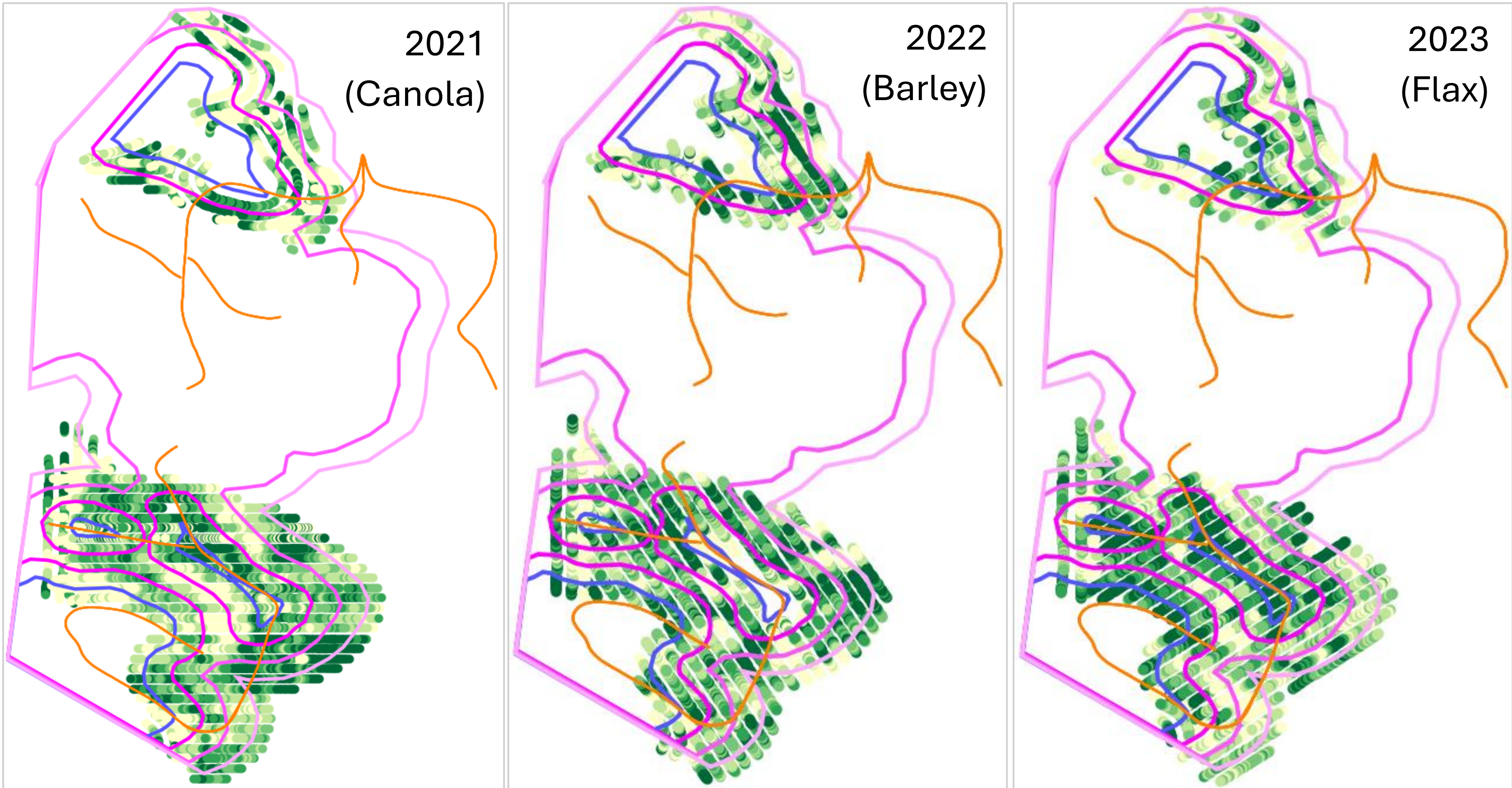


Figure 10. Yield maps showing variation in yield in the zones surrounding the managed wetlands in Field 3 in all three years of the study. Lighter points indicate lower yields and darker points indicate higher yields and were determined for each crop and field separately.

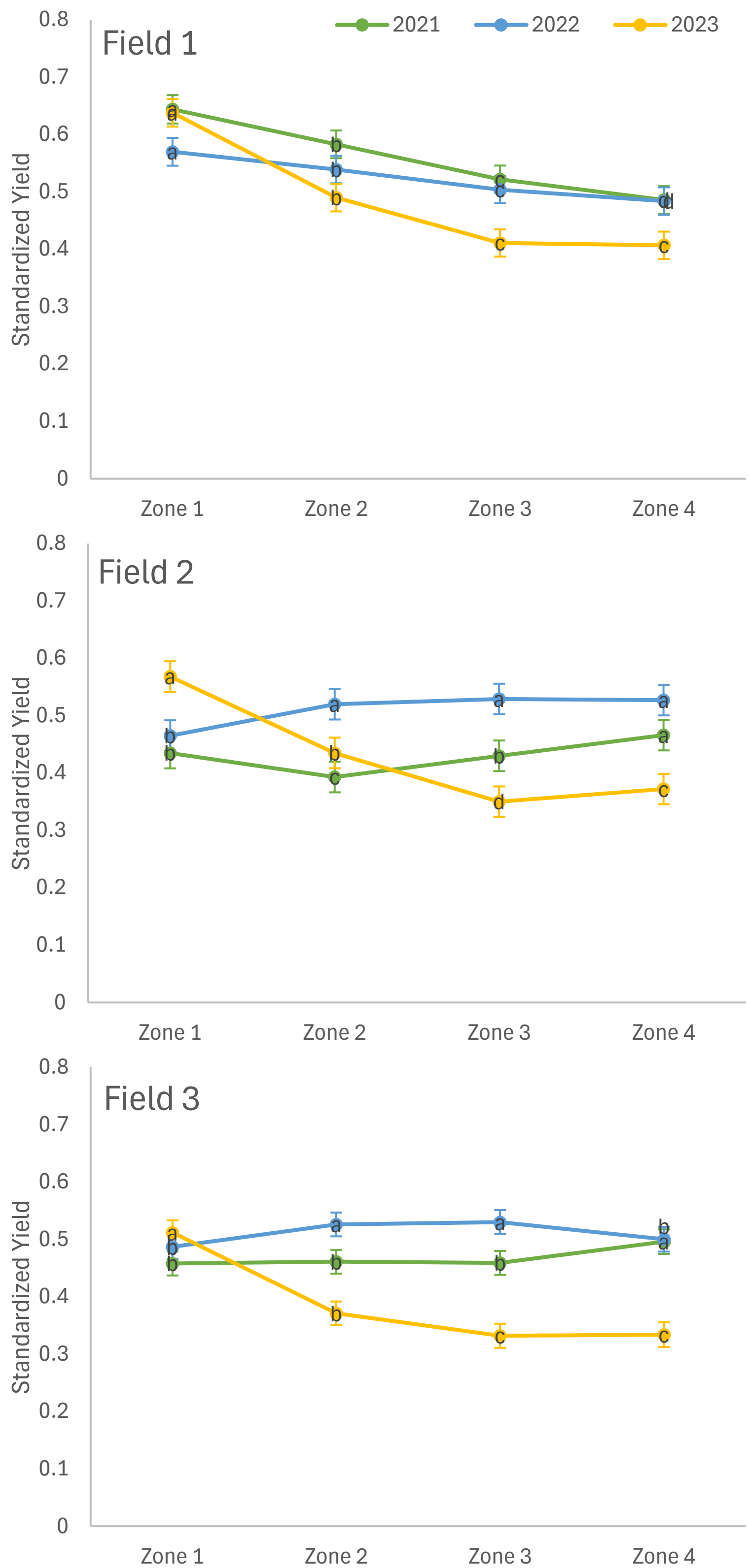


Figure 11. The difference in standardized yield in the four managed wetland zones over the three years of the study. Zones with the same letter are not significantly different (within years for simplicity).

Table 7. Actual mean yields by managed wetland Zone for each field and year.

	Field 1			**Field 2**			**Field 3**		
	2021 Flax	2022 Barley	2023 Canola	2021 Canola	2022 Barley	2023 Canola	2021 Canola	2022 Barley	2023 Flax
Zone 1	24.9	83.4	105.6	29.0	57.7	77.3	26.7	80.6	44.4
Zone 2	23.0	80.4	85.0	26.2	64.1	62.9	26.8	85.4	36.0
Zone 3	21.1	76.9	73.9	28.7	65.1	53.7	26.7	86.0	33.7
Zone 4	20.0	75.0	73.3	31.1	64.9	56.2	28.8	82.2	33.8

Water Quality

Water samples were collected in each field in the spring of 2022 to serve as a baseline for water quality monitoring. Samples were collected from a tile drain outlet, a consolidation water body, and an unmanaged wetland (comparative to the tiled wetland) at the start and end of spring runoff (April 20 and May 5).

Weather conditions during the growing season for each year of the study were variable. 2021 weather was hot and abnormally dry, 2022 was an average year with an early spring melt followed by a freeze cycle which froze water in the tile lines. The tiled potholes took longer for the water to infiltrate out and not drain fully before seeding, resulting in unseeded acres for 2022. 2023 was again on the drier side. Detailed environmental data from a local weather station can be accessed online at Government of Canada Weather Data Reporting – Lipton. Samples were not collected from the tile drain outlet on the second sample date because outlets were below the water level. The data could not be analyzed statistically as the sampling was not replicated but the results were tabulated to assess potential trends.

In all three fields, levels of dissolved phosphorus appeared to be similar in the unmanaged wetland and consolidation water body at the earlier sample time, and lower in the tile outlet (Figure 12). At the later sample time, phosphorus appeared to be higher in the unmanaged wetland. Phosphorus is more likely to move with overland flow of water, and we have also seen in this study that soil phosphorus levels were elevated in Zone 1 of the managed wetlands. A reduction in the overland flow of water with installation of tile drainage may help alleviate the movement of phosphorus in fields under crop production.

Levels of dissolved nitrates were more variable across sample points and fields (Figure 13). In Fields 1 and 2, dissolved nitrate-N appeared to be elevated in the tile outlet and consolidation water body than in the unmanaged wetland. Dissolved N levels were lower overall in Field 3 but again appeared to be elevated in the tile outlet. Dissolved N levels were negligible and did not differ between sample points at the later sampling date and are not shown. Nitrates are more likely to move downwards in the soil with water and it has been shown that tile drainage can contribute to the movement of nitrates in fields under crop production. However, anhydrous ammonia was applied to all three fields in the fall of 2021, and so nitrogen levels in the soil would have been elevated in spring 2022 compared to a year where different N management was utilized. A different source or application timing of N fertilizer, as per 4R best management practices, will help alleviate the issue of N movement with managed water in fields with tile drainage.

Conductivity of the water samples are an indication of salts. This measurement was variable among fields and sample points and it is difficult to identify any trends. Salinity was elevated at the later sampling date compared to the first, this is likely because of the reduced volume of water flow at this time.

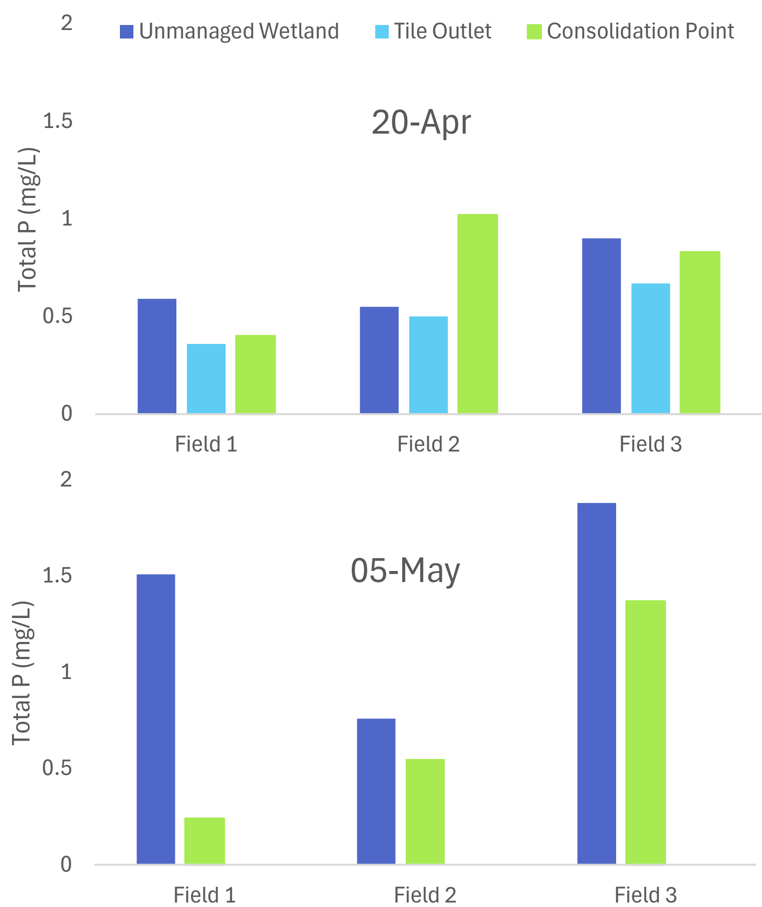


Figure 12. Levels of total dissolved phosphorus (P) in water samples taken from an unmanaged wetland, at the tile outlet, and in the consolidation water body in each of the three fields at early runoff and post-runoff in spring 2022.

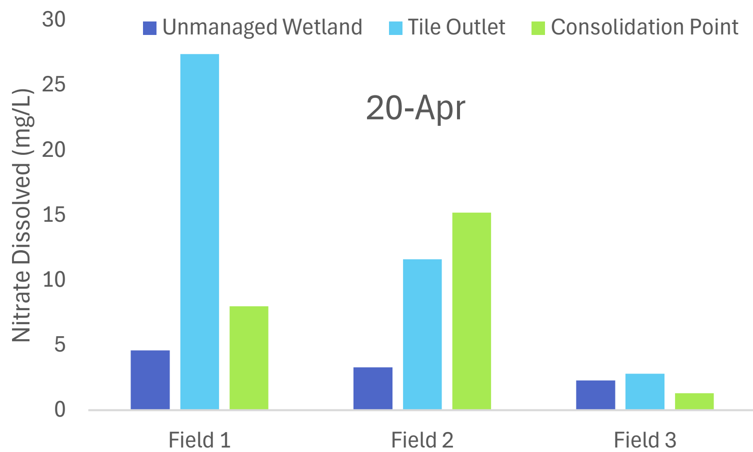


Figure 13. Levels of total dissolved nitrate-N in water samples taken from an unmanaged wetland, at the tile outlet, and in the consolidation water body in each of the three fields at early runoff in spring 2022.

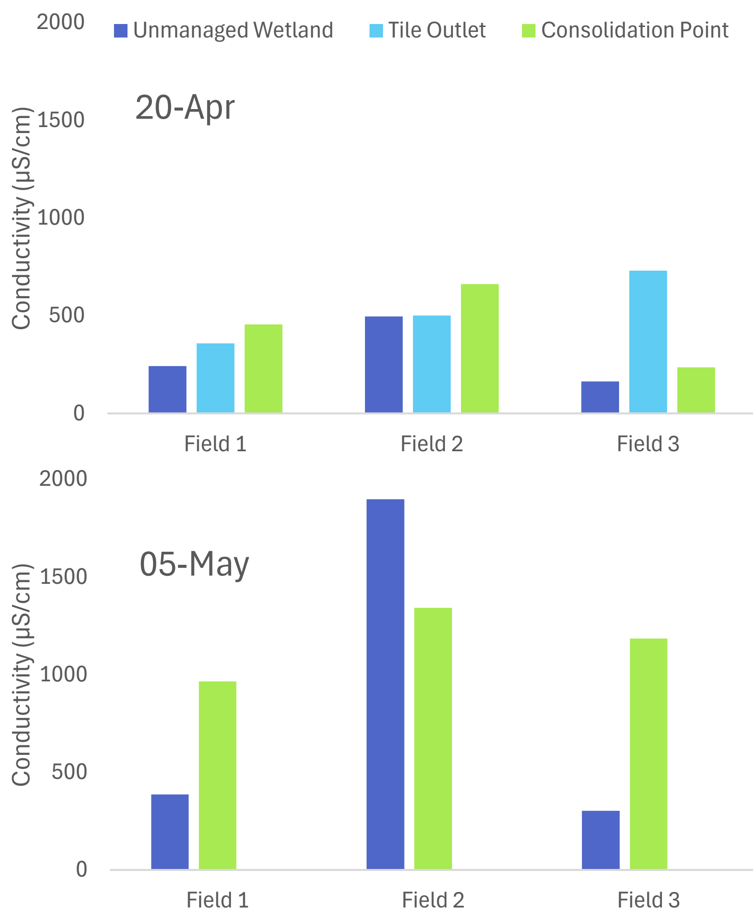


Figure 14. Conductivity (estimate of salinity) of water samples taken from an unmanaged wetland, at the tile outlet, and in the consolidation water body in each of the three fields at early runoff and post-runoff in spring 2022.

Conclusions and Recommendations

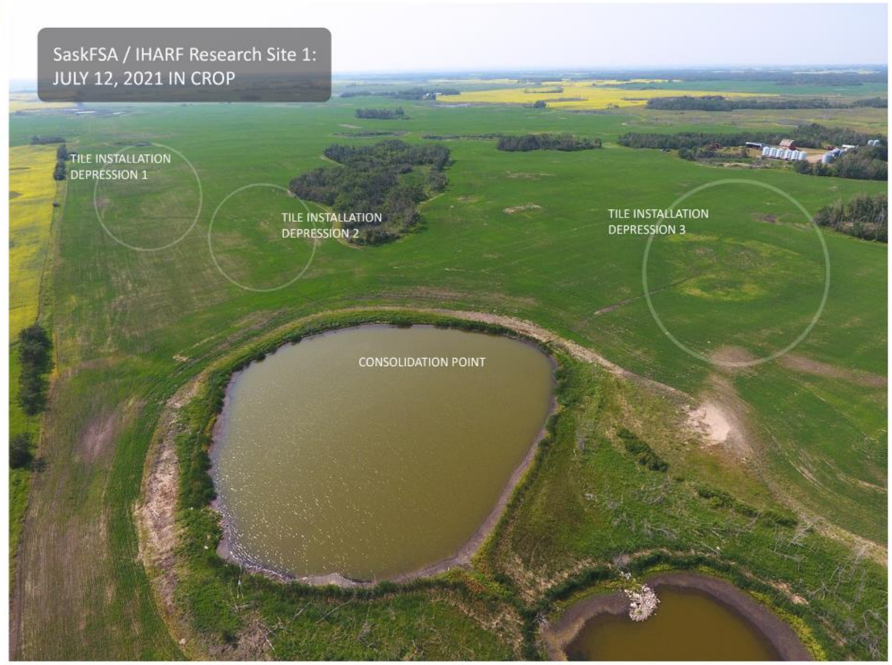
Notable changes in crop productivity were observed over the three years of the study. Previously uncropped areas and marginal areas had significant increases in productivity three years after installation of tile drainage, and this indicates a large economic benefit to tile drainage in pothole landscapes. In future research, it would be beneficial to have delineated cropped areas and have records of crop yields several years prior to the installation of tile drainage, to determine the change in cropped area and productivity over the whole field with and without tile drainage. Similarly, digital product application maps before and after the installation of tile drainage could be utilized to assess the reduction in overlap. This was not possible in this study.

There visually appeared to be a trend in all three fields towards decreasing soluble salts in all soil depths from the initial year to the third year. Soil organic matter and residual phosphorus did not change significantly in the landscape surrounding the managed wetlands over the three years of the study. The change in residual nitrate-N was likely attributable to other crop management factors (anhydrous ammonia (NH_3) was applied to all three fields in the fall of 2021, after a dry growing season with low yield potential).

Soils characteristics are slow to change and may need to be monitored over several years to assess the long-term impacts of tile drainage installation. It is also possible that the installation of tile drainage in fact has negligible effects on soil characteristics, even in the long-term, especially when combined with responsible crop production practices, specifically nutrient management. A more formal water sampling protocol and schedule would also provide better insight on the movement of nutrients in areas influenced by tile drainage in comparison to unmanaged wetlands.

APPENDIX - Aerial Photos

RESEARCH SITE 1. 2021-2024:



Targeted tile drainage installation was completed the fall of 2020. Drone imagery was taken pre-seed 2021, and in-crop 2021 to 2024. Important imagery to demonstrate how landowners use tile drainage to manage excess water from temporary and seasonal farmed through depressions for agronomic, environmental, and economic benefits.

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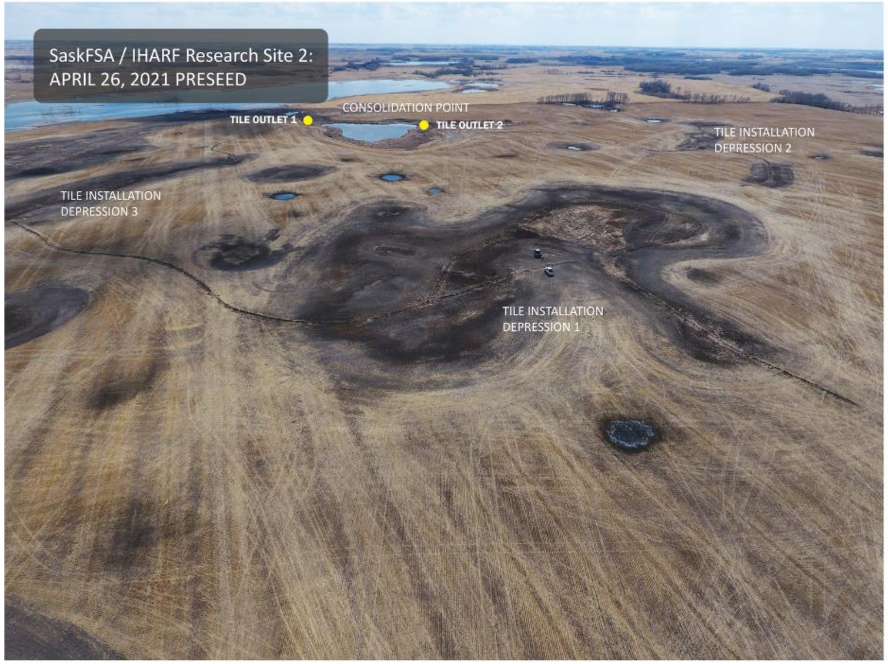

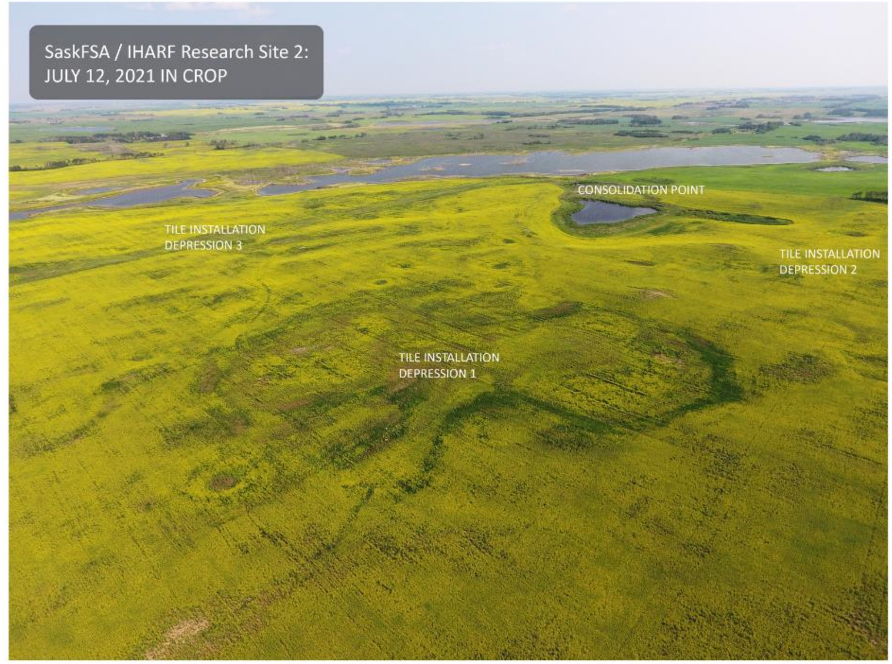

Targeted tile drainage installation was completed the fall of 2020. Drone imagery was taken pre-seed 2021, and in-crop 2021 to 2024. Important imagery to demonstrate how landowners use tile drainage to manage excess water from temporary and seasonal farmed through depressions for agronomic, environmental, and economic benefits.

RESEARCH SITE 3. 2021-2024:

Targeted tile drainage installation was completed the fall of 2020. Drone imagery was taken pre-seed 2021, and in-crop 2021 to 2024. Important imagery to demonstrate how landowners use tile drainage to manage excess water from temporary and seasonal farmed through depressions for agronomic, environmental, and economic benefits.