Project No. A21007P
Date: May 18, 2022
Revised: May 25, 2022
Humboldt, Saskatchewan

Final Report

Research Report

Refining Economic and Agronomic Costs of Wetland Mitigation

For:
Water Security Agency
Moose Jaw, Saskatchewan

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Refining Economic and Agronomic Costs of Wetland Mitigation

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1. Executive Summary

Agronomic and economic potential from agricultural water drainage is dependent on many variables, such as yearly differences, crop type, wetland class, type of drainage (impact code), and more. This study aimed to explore the significant variables that impact agricultural productivity and the overall economic advantages and disadvantages of three different drainage scenarios.

This is an observational study and involves no experimental manipulation. The data analyzed in this study included two Saskatchewan datasets; one located in the Black soil zone, and one located in the Dark Brown soil zone. The data encompassed yield data from multiple years and crop types; however, the four main crops studied included barley, canola, yellow peas, and wheat.

The agronomic analysis was defined by two main comparison groups: yield data in the wetland itself and yield data in the buffer area (5-50-meter incremental buffer zones). The yield data in the wetland included only wetlands that were farmed (but not drained) or completely drained, whereas the buffer area included data from wetlands that were farmed, drained, partially drained, and intact. This data was analyzed using RStudio to determine the significance of each variable studied (year, crop type, wetland class, impact code, buffer distance, etc.) as well as interactions between the variables. The results differed in significance between some variables within the two datasets but some similarities were also found.

Yield response from the wetland itself varied greatly. Across both datasets, yield was significantly higher (range) in the 50-meter buffer zone 11.8% to 24.9% for farmed and completely drained zones when compared to wetlands. This trend generally held for most crop types and classes of wetlands.

Crop response across both datasets also showed similar results with, on average, farmed and completely drained wetlands yielding significantly higher than intact and partially drained wetlands for all four of the crop types studied (barley, canola, yellow peas, and wheat).

Economic models for each data set were created based on yield response in each field zone (buffers, wetlands, and uplands) according to impact code to drive three scenarios. The mitigation scenario was based on the data as collected which included a distribution of intact, partially drained, farmed, and completely drained wetlands. A fully drained scenario was simulated by driving the intact wetland and buffer zone areas within the model with data from the fully drained wetland and buffer zones. A no-drain scenario was simulated by driving the fully drained zones with data from the intact wetlands and buffer zones. Crop values and agronomic assumptions were applied based the

Saskatchewan Crop Planning Guide. Consistently, the models showed an economic net benefit in favour of draining wetlands of $18 to $33 per cultivated acre. A sensitivity analysis revealed three distinct effects. First, sectional control eliminated much of the benefit of wetland drainage by reducing the cost of overlapping farm inputs. Second, drainage was still profitable even if costs in the model for drainage install was more than doubled. Third, in the absence of the overlap effect, the increase in margin by drainage was largely driven by the yield increase in the buffer zone surrounding the wetland.

2. Introduction

Water management is crucial for on-farm productivity for both crop production and operating efficiencies. The key for proper water drainage is balancing the positive effects of drainage (i.e., increased agricultural production and creating a balanced economy) with the need to remain environmentally sustainable (i.e., retaining water and protecting habitat). Retaining wetlands may result in reduced efficiency (e.g., increased mechanical overlap or greater time for maneuvering through fields, i.e., nuisance costs), which can cause adverse environmental effects from product overapplication, decreased crop productivity, and potential in-season management issues. However, draining wetlands can be a costly endeavor and may not provide a positive agronomic or economic return on investment.

Many wetlands in the Prairies are associated with salinity. Saline soils are unsuitable for many crop types (e.g., pulse crops) and have a negative effect on many oilseed crops. Though cereal crops tend to be more salt tolerant, excess salinity levels will result in reduced crop yield. Salinity is a widespread water-management problem, which is caused by:

- soluble salts rising up through the soil profile with excess water, resulting in concentrated salts in the surface horizons as the soil water evaporates, or
- excess water from recharge zones moves to and collects in poorly drained discharge zones, concentrating the salts in these zones (Manitoba Agriculture, 2008). **Figure 1** shows the recharge and discharge zones.

Salinity causes crop stress by preventing the roots from performing essential osmotic activity where water and nutrients are moved into the plant, resulting in adverse affects on seedlings (Alberta Agriculture and Rural Development, 2001).

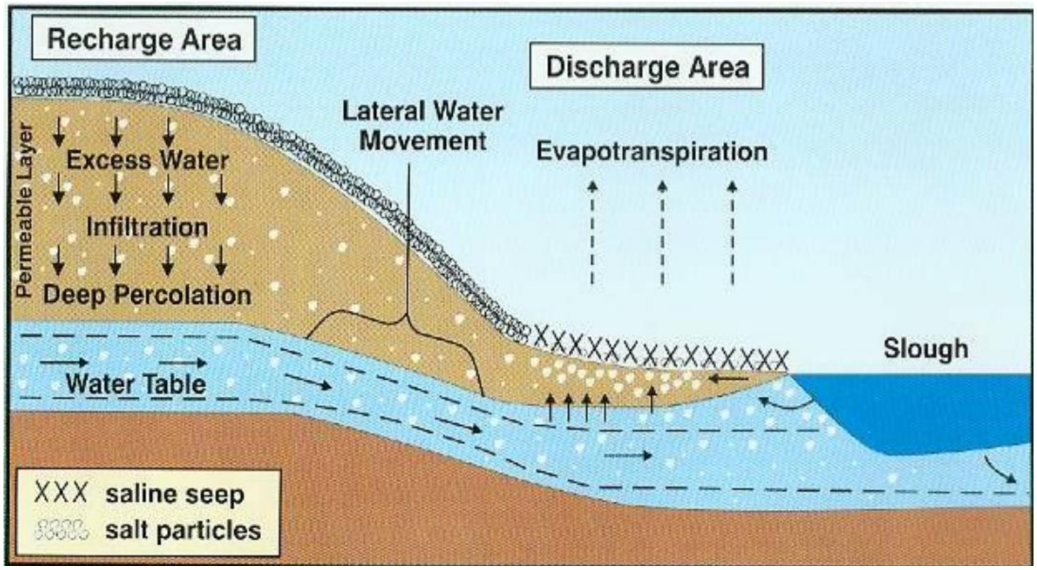

Figure 1. Salinity by water recharge and discharge areas **(Manitoba Agriculture, 2022)**.

Waterlogged soils can also be detrimental to crop growth. Areas prone to waterlogging can result in delayed seeding, potential re-seeding scenarios, reduced crop yield, increased disease risk, and more. Proper water management may aid in reducing the impact of saline and waterlogged soils on crop production.

Wetlands also provide many benefits on farm including effects on overall groundwater hydrology, habitat for many organisms and diverse vegetation species, water filtration system, as well as potential for powerful carbon sinks. Though there are many benefits of wetlands on farm, the variables determining the agronomic and economic effects of draining them or farming around them have not been fully studied or understood well enough to use as a baseline in different farming and management scenarios.

The agronomic and economic effects of retaining, partially draining, or fully draining wetlands may be affected by many variables including environmental conditions, crop type, input costs, drainage costs, wetland permanence class, impact code, nuisance and overlap costs, and more. Wetland class refers to average amount of time water remains in a wetland through the growing season (temporary, seasonal, semi-permanent, permanent). Drainage status is described in this study by impact code (intact, farmed – but not drained, partially drained, fully drained). Nuisance and overlap costs can be directly related to machinery needing to maneuver around the wetlands, resulting in increases in total path length, operation time, and product overlap. This study encompasses the agronomic and economic results of two datasets on varying levels of wetland drainage.

3. Project Objective

This project is Phase 2 of the previously defined *Agronomic and Economic Evaluation of the Drainage Mitigation Demonstration Projects*. Phase 1 focussed on exploring methodology to best evaluate effects of drainage, derived from data from the Dark Brown soil zone. This project aimed to further define the methodology of the agronomic and economic evaluations completed in Phase 1. A key point is that this is an observational study rather than one involving experimental manipulation and it is the first time this type of evaluation has been reported in literature. It also means that the results should be substantiated by more work.

The first objective was to refine the agronomic analysis of the Dark Brown Soil Zone from Phase 1. A total of 20 fields located in the Dark Brown soil zone (selected by the WSA) were analyzed over 4 years of data. Statistical analyses determined the levels of significance of each variable on the yield, which was summarized to reflect the effects of wetlands on yield.

The second objective was to analyse additional yield data from the Black Soil Zone. A total of 16 different fields located in the Black soil zone were selected by the Water Security Agency (WSA; the Client) with up to 7 years of data was collected from each field (if available) including yield data, crop type, wetland class, impact code. The methodology and refined analysis used in the Dark Brown Soil Zone study was applied.

The third objective was to revise the economic model developed in Phase 1 using the new agronomic results from Phase 2. Economic models for each data set were created based on yield response in each field zone according to impact code to drive three scenarios. The Mitigation scenario was based on the data as collected with wetland impact codes 0, 1, 2, and 5. A Fully Drained scenario was simulated by driving the impact code 0 and 1 zones with impact code 5 data. A No Drain scenario was simulated by driving the impact code 5 zones with impact code 0 data. Crop values and agronomic assumptions were applied based the Saskatchewan Crop Planning Guide. The economic models were used to determine the net benefit of wetlands by contrasting results of the three scenarios.

4. Project Description

This project refined the methodology created in Phase 1 for both the agronomic and economic analyses. Data from the Dark Brown soil zone was reanalyzed, along with a new data set from the Black soil zone (Section 5.2.1). A revised interpolation technique was used on the yield data. The revision was made to create a tighter grain of spatial data and provide a more accurate representation of the data. Within this project, Prairie Agricultural Machinery Institute (PAMI) refined methodology to study the impact of wetlands on the agronomics (i.e., crop yield and field efficiency) and economics in various wetland drainage scenarios. This study includes data within only a 50-meter buffer around each wetland. The yield data for the analysis was pulled from the combine and relativized to account for field and year effects (and because it was unknown whether the yield monitors were calibrated).

Two of the driving variables in this analysis included impact code and wetland class. Impact code defines the level of drainage of the wetland, whereas wetland class defines the permanence of the wetland itself. Statistically, wetland classes 1 and 2 were considered the same, and were therefore merged and labeled as “wetland class 2” for this study. The definitions of the impact codes and wetland classes are further defined in **Table 1** and **Table 2**, respectively.

Table 1. Impact codes defined (Water Security Agency, 2020).

Impact Code	Definition
0	**Intact** - no evidence of drainage
1	**Partially Drained** – the water level has been lowered, but the soil contains enough moisture to support hydrophytes
2	**Farmed** – the soil area has been altered for the production of crops (but remains undrained), but if farming is discontinued hydrophytes will become re-established
3	**Constructed** – the soil area has been excavated to create a water-holding basin
4	**Partially Filled** – the basin shows evidence of clearing
5	**Completely Drained** – the soil surface has been altered for the production of crops, and the water level has been lowered

Table 2. Wetland classes defined (Alberta Wetland Policy, 2020).

Wetland Class	Definition
1	**Ephemeral** – the wetland has free surface water for a short period of time
2	**Temporary** – the wetland is periodically covered by water, lasting only a few weeks
3	**Seasonal Ponds and Lakes** – the wetland usually dry by midsummer
4	**Semi-permanent Ponds and Lakes** – the wetland frequently maintains surface water throughout the growing season
5	**Permanent Ponds and Lakes** – the wetland has permanent open water

Interpolated combine yield data was used to create a map for entire fields and generate the values for the wetland and 50-meter buffer. These values were then analyzed in

5-meter increments from the wetland with buffer zone “0” referring to the wetland area itself.

Precipitation data for the Black soil zone was summarized by using three weather stations (Elkhorn 2 East, MB; Virden, MB; and Kipling, SK) to support the agronomic interpretation of the results from the analysis (Government of Canada, 2022). The precipitation data (in millimeters) is highlighted by year for each of the three weather stations in **Table 3** and by month (May to September only) in **Table 4**. This data was not used in the statistical analysis itself and acted as a supporting reference. The entire monthly precipitation data by year can be found in **Appendix A.**

Table 3. Black soil zone analysis precipitation (mm) by year, by weather station location.

Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Elkhorn 2 East, MB	629	403	623	362	457	400	316
Virden, MB	-	588	338	246	365	459	263
Kipling, SK	604	420	591	273	452	477	280
Average	617	470	517	294	425	445	286

Table 4. Black soil zone analysis precipitation (mm) in May to September, by weather station location.

		2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Elkhorn 2 East, MB	**May**	61.4	18.4	80.2	17.0	51.9	23.4	22.6
	June	225	59.0	92.6	85.8	125	42.6	87.4
	July	23.2	126	105	24.0	46.8	45.2	56.8
	August	114	49.4	19.4	38.2	20.4	82.8	24.2
	September	49.6	44.4	68.6	59.6	72.4	109	17.4
Virden, MB	**May**	64.6	55.8	55.8	15.4	62.8	23.7	19.0
	June	131	82.9	2.60	34.0	101	80.6	60.0
	July	40.5	173	29.6	3.20	56.9	35.1	118
	August	124	76.6	6.40	41.4	24.7	118	6.00
	September	25.5	52.4	63.8	97.6	73.0	117	13.6
Kipling, SK	**May**	61.8	20.8	86.6	25.2	49.1	14.4	23.0
	June	191	38.6	101	98.2	149	115	44.2
	July	21.2	72.0	85.8	12.6	49.4	34.4	42.6
	August	116	51.8	39.2	21.4	27.0	88.0	68.4
	September	56.2	73.2	54.6	22.2	35.4	113	20.6
Average	**May**	62.6	31.7	74.2	19.2	54.6	20.5	21.5
	June	182	60.2	65.4	72.7	125	79.4	63.9
	July	28.3	124	73.5	13.3	51.0	38.2	72.5
	August	118	59.3	21.7	33.7	24.0	96.3	32.9
	September	43.8	56.7	62.3	59.8	60.3	113	17.2

It must be noted (as displayed in **Appendix A**) that the majority of the precipitation recorded at the Virden, MB, station in 2014 happened in February and March, which resulted in a flood situation.

Precipitation data the Dark Brown soil zone was summarized from the stations nearest to the project sites and were also gathered from the Government of Canada historical weather data website (Government of Canada, 2022). This information was used to support the agronomic interpretation of the results from the analysis and was not used statistically in the analysis. This data is summarized in **Table 5** and **Table 6**, representing a full year of precipitation and growing season data (May to September), respectively. The entire monthly precipitation data by year can be found in **Appendix A**.

Table 5. Dark Brown soil zone analysis precipitation (mm) by year, by weather station location.

Year	2016	2017	2018	2019
Last Mountain CS, SK	382	229	247	256
Moose Jaw CS, SK	515	218	229	405
Regina RCS, SK	437	152	204	375
Average	445	200	226	345

Table 6. Dark Brown soil zone analysis precipitation (mm) in May to September, by weather station location.

		2016	2017	2018	2019
Last Mountain CS, SK	**May**	50.6	10.8	34.4	11.4
	June	39.5	27.2	76.6	68.2
	July	128	5.10	22.5	6.60
	August	33.0	51.5	17.7	58.4
	September	38.1	22.8	35.4	64.3
Moose Jaw CS, SK	**May**	101	12.7	32.8	3.50
	June	58.6	34.4	47.0	112
	July	81.8	4.30	20.1	29.9
	August	64.1	43.9	18.1	86.9
	September	49.0	7.30	31.5	105
Regina RCS, SK	**May**	73.5	6.90	25.4	11.3
	June	58.3	46.0	43.9	76.7
	July	74.3	1.80	19.5	50.3
	August	58.3	11.1	17.4	95.7
	September	54.0	11.1	27.6	78.5
Average	**May**	74.9	10.1	30.9	8.70
	June	52.1	35.9	55.8	85.5
	July	94.5	3.70	20.7	28.9
	August	51.8	35.5	17.7	80.3
	September	47.0	13.7	31.5	82.5

4.1 Agronomic Statistical Evaluation

The agronomic statistical evaluation analyzed many variables including impact code, wetland class, buffer zone, yield (as a percentage of total field average), crop type, year, and more (full details can be found in **Appendix B**). These variables were analyzed as single variables, as well as interactions between all. The dependent, or response variable was crop yield, which was defined as a percentage of the total field average (therefore, 100% in the data would represent field average).

The refined data was then analyzed in the program RStudio (RStudio Team, 2021) through similar methodology as Phase 1, though some steps were modified. A summary of the data points for both datasets are listed below with accompanying yield data shown in the histograms in **Figure 2** to **Figure 7**.

Black Soil Zone Dataset

- 48,734 data points (representing either a wetland or a 5-meter buffer polygon).
- 7 years (2014 to 2020, inclusive).
- 16 fields.
- 4 crop types (malt barley, canola, spring wheat, and yellow peas).

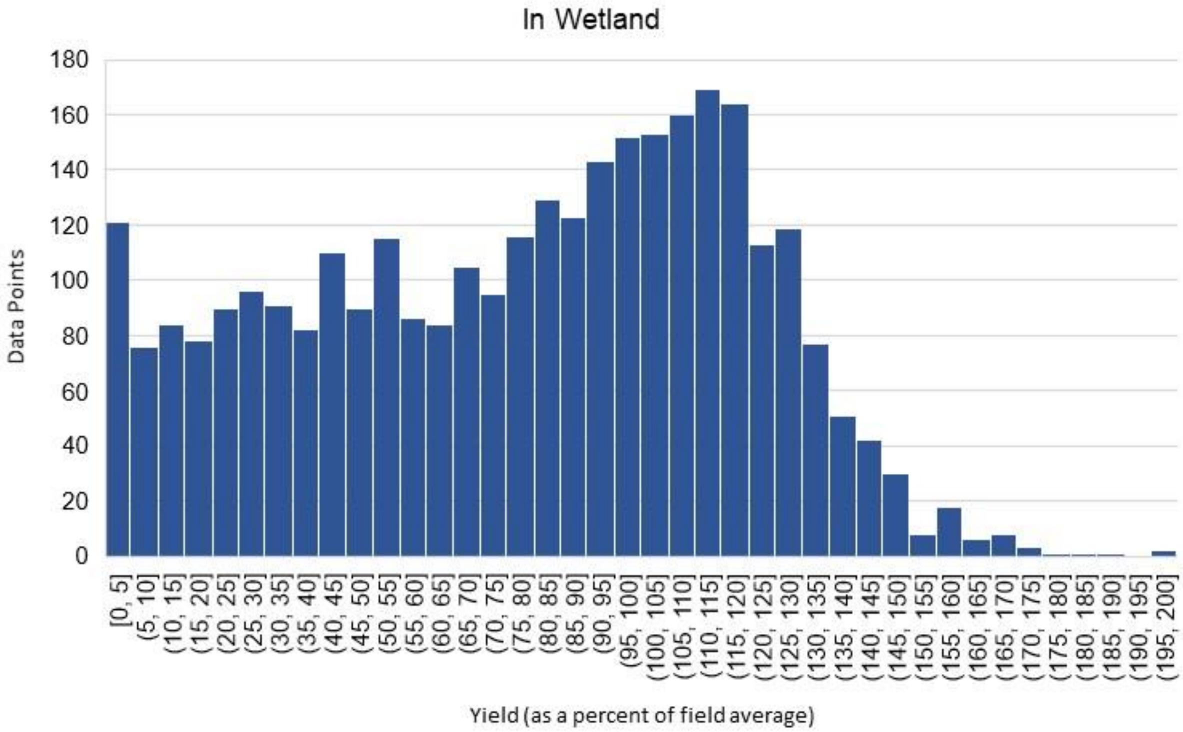

Figure 2. Histogram of data distribution for yield (as a percent of field average) in the wetland of the Black soil zone dataset.

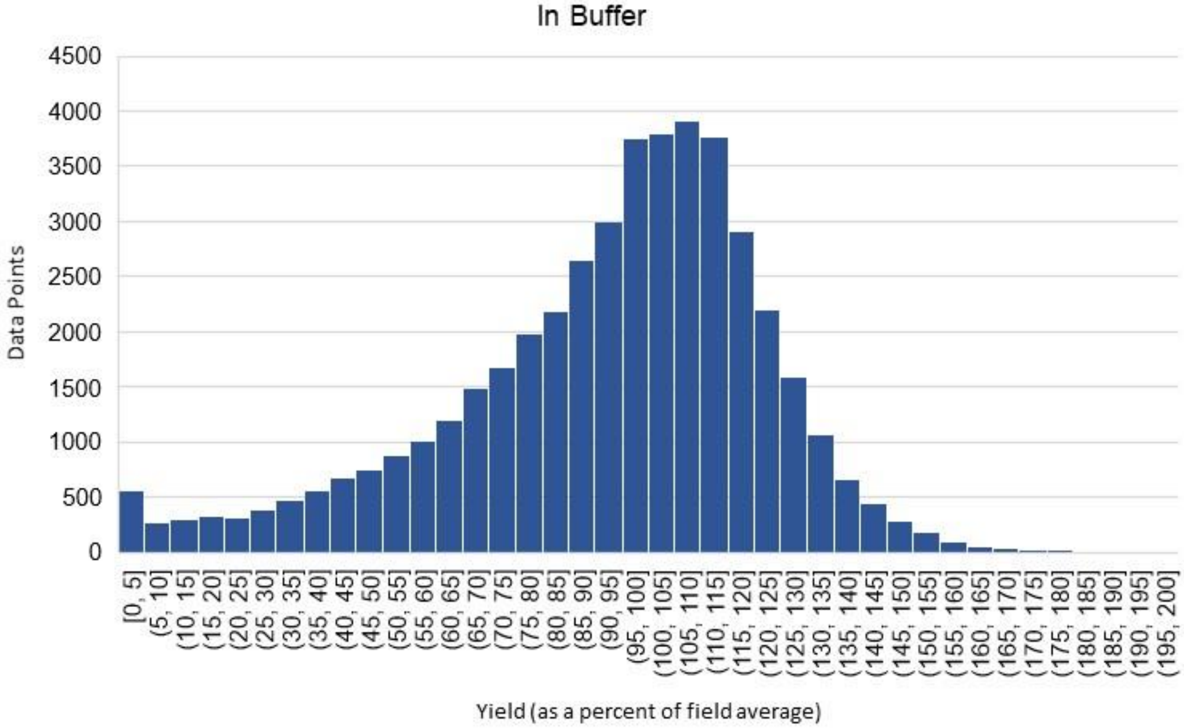

Figure 3. Histogram of data distribution for yield (as a percent of field average) in the buffer of the Black soil zone dataset.

Dark Brown Soil Zone Dataset

- 29,715 data points (representing either a wetland or a 5-meter buffer polygon).
- 4 years (2016 to 2019, inclusive).
- 20 fields.
- 4 crop types (malt barley, canola, spring wheat, and yellow peas).

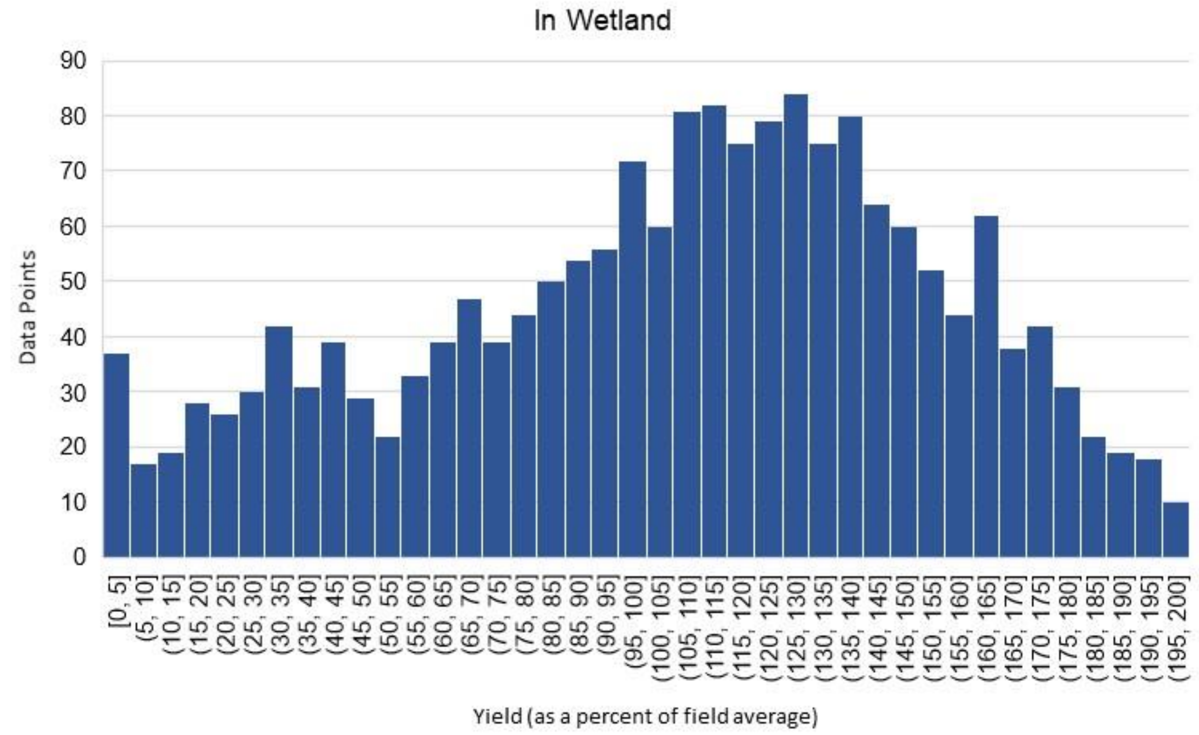

Figure 4. Histogram of data distribution for yield (as a percent of field average) in the wetland of the Dark Brown soil zone dataset.

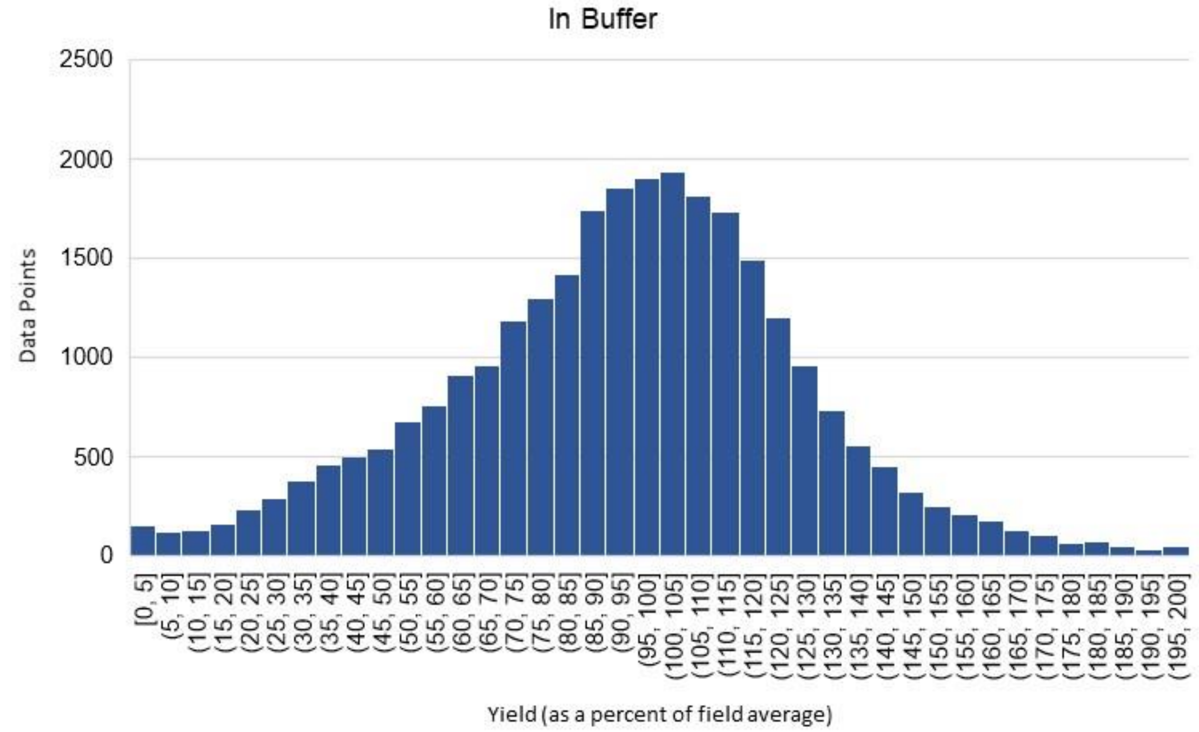

Figure 5. Histogram of data distribution for yield (as a percent of field average) in the buffer of the Dark Brown soil zone dataset.

A backward stepwise regression method was used to develop the statistical model; a significance level of $\alpha = 0.05$ was used. Tukey's Honest Significant Difference test with a confidence level 95% was used to determine meaningful differences between treatment levels. This method was chosen as it provides the ability to test multiple groups against each other while accounting for multiple comparisons.

4.2 Economic Evaluation

The base set-up of the economic evaluation was derived from the Saskatchewan Crop Planning Guide (**Appendix F**). The annual cropping cost of production can change annually with commodity prices, crop input values, as well as other variable expenses. The "general assumptions for all soil zones" listed in the Crop Planning Guide were applied to this model. The four chosen crop types were pulled from the agronomic evaluation and applied to this model based on equal areas of rotation.

4.2.1 Drainage Scenarios

A spreadsheet-based economic model was built to explore three drainage scenarios: full drainage, mitigation, and no drainage. The model was designed to be an active worksheet where relevant values can be interchanged for each evaluation scenario.

1. **Full Drainage Scenario**
   a. Full drainage assumes all wetlands have been drained and essentially all of the land is farmed. In this scenario, the nuisance and overlap costs are both zero. Impact code 2 (farmed, not drained) remains from the collected data but all other wetlands are analyzed based on impact code 5 yield data for this model simulation.
2. **Mitigation Drainage**
   a. The mitigation scenario is a partially drained scenario that is based on the current state of fields from which data was collected. Wetlands of impact code 0, 1, 2, and 5 all exist in this scenario (some drainage has been done, but there are wetlands still remaining).
3. **No Drainage**
   a. The no-drainage scenario is based solely on farming impact code 2 (farmed, not drained) wetlands. Drainage costs go to zero, and in this scenario, wetlands of impact codes 0, 1, and 5 are not farmed and are all simulated as impact code 0.

4.2.2 Model Variable Definitions

The methods to determine the baselines for each drainage scenario and the assumptions made to apply these to the model are listed with the model variable definitions below.

1. ***Drainage Cost Assumptions:***
   a. **Drainage installation:** The excavation cost of a wetland to be drained is based

on the Client’s experience and/or supporting data and was set at $4 per cubic meter. This assumes landowners performing the work themselves could do so in a more cost-effective way. There are a variety of methods for drainage ditch installation, including surface ditches and tile installation. For these economic models, it was assumed that surface ditches with shallow side sloping would be installed, as they allow for farming through. This is followed by the assumption that a completely drained field can be completely cultivated with no nuisance cost; that is, there would be no steep ditches interrupting implement path.

   b. **Drainage maintenance:** The drainage maintenance cost for this report is assumed to be zero; that is, it is assumed to be covered by the cost of drainage installation. It is understood that some maintenance to the drains is necessary, especially in the first few years following initial installation. This report assumes that this maintenance cost would be minimal and that would diminish to zero after the drains have become established.

   c. **Amortization of Drainage Costs:** Based on the Client’s experience and/or supporting data, an interest rate of 5% was used to amortize over 25 years to account for drainage installation as an annual cost.

2. **Farming Variable Expenses:** Farming variable expenses are based on assumptions made in the Crop Planning Guide 2022 (**Appendix F**).
3. **Nuisance and Overlap Cost:** There are two aspects to the additional farming costs associated with retaining wetlands:
   a. **Nuisance Cost:** is defined as the percentage of extra distance driven by an implement per farmed unit area.

   b. **Overlap Cost:** the percentage of extra crop input applied due to overlapping areas previously covered areas. The percentage of overlap was calculated by dividing the area sprayed/seeded by the cultivated acres in the field.

   Preliminary cost estimates were made based on machinery path data collected from the Dark Brown soil zone data set for seeding and spraying. The analysis of this data is further discussed in **Section 8**.

4. **Crops in Production:** This model is based on equal-area crop rotations. In the Dark Brown soil zone economic model, three crops were included: spring wheat, canola, and yellow peas. In the Black soil zone economic model, four crops were included: spring wheat, canola, malt barley, and yellow peas. The yield data of these crops was used to calculate the yield response index applied to the field study zones described below. Yield response index is defined in **Section 8**.
5. **Field Study Zones:** The field study zones used in the economic evaluation were based on a refinement of the collected raw data. This was done for basic economic model development, which is based on the unique yield response for the various field study zones. The data analysis revealed a yield response as a percentage of field

average for each wetland and the associated buffer zone according to the impact code. The yield response index is defined in the agronomic analysis results in **Section 6 and 7.** Future work is intended to further define the economic analysis to a broader array of data from different farms, soil zones, and crop types. For this study, the field study zones are defined as:

a. Wetland Area: including drainage impact codes 0, 1, 2, and 5.
b. Buffer Zone Area: This includes a border of 50 m beyond the wetland by impact codes 0, 1, 2, and 5. The buffer zone raw data includes overlapped areas that occur when wetlands are less than 100 m apart. The buffer zone correction factor for buffer overlap is defined in **Section 5**.
c. Non-Buffer Zone Area: This includes remaining field area not defined by wetland or buffer zone. This zone is also taken as the baseline for yield based on the data from the Saskatchewan Crop Planning Guide 2022.
d. Total Field Area: This is the sum of all zones in a field, which accounts for the total area.

The total field area of the Dark Brown soil zone economic analysis was 10,433 acres which included 637 acres of wetland and 4,486 acres of buffer zone.

The total field area of the Black soil zone economic analysis was 4,689 acres which included 446 acres of wetland and 2,873 acres of buffer zone.

These field study zones area as highlighted in **Figure 4**.

a. Upland = buffer + non-buffer
b. Cultivated = buffer + non-buffer + farmed wetlands
c. Total Field Area = upland + farmed wetlands + wetlands

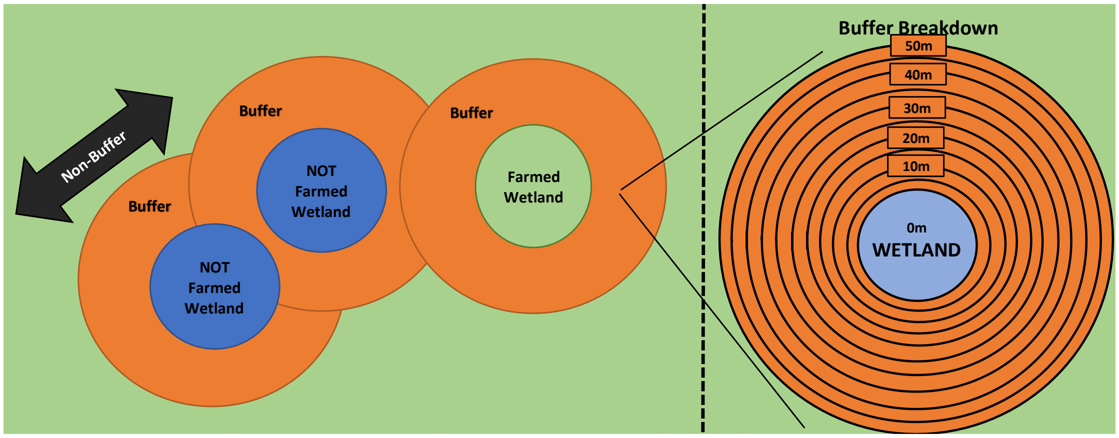

Figure 6. Buffer-zone overlap definitions for upland area, cultivated area, and total field area.

6. **Sectional Control** is a technology that reduces the overapplication of crop inputs from implement overlap when seeding or spraying around in-field obstacles or when any irregular boundaries are navigated. Generally, the technology is based on the

ability to turn off crop inputs to individual sections of the implement when said sections encounter previously planted or sprayed areas. The result is a reduction in the application of crop inputs from what would normally be applied if no sections of the implement were shut off. The ratio of extra crop inputs that would be applied without sectional control over the inputs actually applied is the sectional control reduction factor and describes the effectiveness of using sectional control technology. For this report, a sectional control reduction factor of 8 was used. That is, it was assumed that for field areas where the implement overlapped previous application, the cost of those inputs is 8 times less. This assumption was made on the Client’s recommendation for the current average effectiveness of sectional control used by farmers in Saskatchewan. The effectiveness of any given sectional control technology can vary greatly and is improving from year to year.

5. Statistical Analysis Results

Details of the statistical analysis conducted on data from both the Black and Dark Brown soil zones is provided in this section. Methodology choices, model forms, and results are discussed.

The quantity of interest was the measured yield in each field polygon; yield was reported as a percentage of field average. One of the key outputs from these analyses were the analysis of variance (ANOVA) tables. The variables reported in these tables are defined below (Bevans, 2020).

- **Df column**: degrees of freedom from the independent variable (the number of levels in the variable minus 1), and the degrees of freedom for the residuals (the total number of observations minus one, and minus the number of levels in the independent variables).
- **Sum sq column**: displays the sum of squares (i.e., the total variation between the group means and the overall mean).
- **Mean sq column**: mean of the sum of squares, calculated by dividing the sum of squares by the degrees of freedom for each parameter.
- **F-value column**: test statistic from the F test. This is the mean square of each independent variable divided by the mean square of residuals. The larger the F value, the more likely it is that the variation caused by the independent variable is real and not due to chance.
- **P-value column**: the p-value of the F-statistic. This shows how likely it is that the F-value calculated from the test would have occurred if the null hypothesis of no difference among group means were true.

5.1 Statistical Analysis of Black Soil Zone Dataset

The following subsections provide the statistical analysis of the Black soil zone data that was collected for this study.

5.1.1 Statistical Analysis Procedure

The raw data was refined in multiple ways to ensure accurate data was used for the analysis. Refinement of this data and statistical analysis methodology is as follows:

1. Raw Black soil zone data loaded into RStudio.
2. Rows (records) with N/A values in Wetland Class, if any, were removed.
3. Dependent values (buffer zone, year, impact code, wetland class, crop type, and field) in each record were parsed as fixed factors with the levels indicated in **Table 7**.
4. Records of yield values that exceeded 200% (65 data records) of the field average were removed.
5. Records for rye, winter wheat, and soybeans were removed (1,390 records) from the

analysis due to lack of sufficient data for the model (leaving malt barley, canola, spring wheat, and yellow peas). 49,453 records being used in the analysis.

6. Records associated with buffer zone “0” were removed for impact codes of intact (0) and partially drained (1) as the 0-meter buffer zone reflected the wetland polygon itself because these areas are assumed to be not cropped.
    a. One ANOVA was conducted on the subset of the data with buffer zones 5-50-meters (including all impact codes) resulting in an analysis of yield outside the wetland itself.
    b. A second ANOVA was conducted on data with buffer zone 0-meters, only with impact codes 2 and 5 (farmed and completely drained) resulting in an analysis of yield in the wetland only.
7. A linear model (*“lm()”* function in base R package (R Core Team, 2021)) was fit to each subset of data.
8. An analysis of variance (*“Anova()”* function from “car” package (Fox & Weisberg, 2019)) using type-II sum of squares was performed on each linear model from 8). F-tests were reported. When running the analysis, if a variable did not display a statistical significance, it was removed from the ANOVA, and the ANOVA was run again. Model terms were deemed statistically significant at $p < 0.05$.
9. Tukey honest significant differences (*“TukeyHSD()”* function in “stats” package (R Core Team, 2021)) were computed for both models. A confidence level of 0.95 was used for both models. This function does adjust for sample size so as to provide “a reasonable interval for mildly unbalanced data” (R Core Team, 2021).

Table 7. Factors and levels included in the final models. The variable label used through the statistical outputs is shown in second row.

Year	**Crop type**	**Buffer zone**	**Impact code**	**Wetland class**	**Field**
year	*crop*	*d_buffer*	*impactcode*	*w_class*	*field*
2014	Canola	0	0	2	Dunham
2015	Wheat	5	1	3	NW-14
2016	Barley	10	2	4	Vics
2017	Yellow peas	15	5	5	Hogard
2018		20			Mccon
2019		25			Chucks
2020		30			Lipsey
		35			HLC_Ho
		40			Bisset
		45			Roy_Ya
		50			FFA_ra
					Swallo
					Bauche
					R_Oliv
					Roys
					Mel_1

5.1.2 Statistical Model Forms

For both datasets, a linear model was developed. First, two-way interactions were attempted with all factors; interactions with *field* created incomplete blocks, so it was included without interaction in the wetland model. The *field:d_buffer* interaction was significant in the in-buffer (5-50-meter buffer zone) model.

The final model form for the data in the wetland (0-meter buffer zone, with impact codes 0 and 1 removed) was:

yield_as_percent_of_field ~ (impactcode + crop + w_class+ year)^2 - year:w_class - crop:w_class - crop:year + field

In the process of developing the model, the interactions *crop:w_class* and *year:w_class* were found to be insignificant. Those terms were removed, and the model was re-run to arrive at the form noted above. The results of an ANOVA of that model are given in **Table 8**.

Table 8. ANOVA results of statistically significant variables of total yield (as a percentage of field average) in the wetland only (0 m) for the black soil zone dataset.

Response:	**Yield as a percentage of Field Average**			
	Sum Sq	**DF**	**F value**	**P-value**
crop	23102	3	6.52	0.0002
impact code	16697	1	14.14	0.0002
wetland class	145818	3	41.16	0.0000
year	569021	6	80.30	0.0000
field	260003	15	14.68	0.0000
crop: impact code	21477	3	6.06	0.0004
impact code: wetland class	22248	3	6.28	0.0003
impact code: year	33005	6	4.66	0.0001
Residuals	3721411	3151		

The final model form fit to the data in the buffer zone (5-50-meter buffer zone) was:

yield_as_percent_of_field ~ (impactcode + crop + w_class+ year + d_buffer)^2 + d_buffer:field - d_buffer:impactcode - year:crop + field

In the process of developing the model, the interaction *d_buffer:impactcode* was not found to be significant. This term was removed, and the model was re-run to arrive at the form above. The results of the ANOVA are given in **Table 9**.

Table 9. ANOVA results of statistically significant variables of total yield (as a percentage of field average) in the buffer zone only (5-50 m) for the black soil zone dataset.

Response:	**Yield as a percentage of Field Average**			
	Sum Sq	**DF**	**F value**	**P-value**
crop	58977	3	26.91	0.0000
buffer	948085	9	144.21	0.0000
impact code	1203141	3	549.02	0.0000
wetland class	907165	3	413.96	0.0000
year	490263	6	111.86	0.0000
field	1038480	15	94.78	0.0000
crop: buffer	64322	27	3.26	0.0000
crop: impact code	149967	9	22.81	0.0000
crop: wetland class	32126	9	4.89	0.0000
buffer: wetland class	205946	27	10.44	0.0000
buffer: year	322109	54	8.17	0.0000
impact code: wetland class	265906	9	40.45	0.0000
impact code: year	300322	18	22.84	0.0000
wetland class: year	90931	18	6.92	0.0000
buffer: field	247729	135	2.51	0.0000
Residuals	33014951	45196		

5.1.3 Type-II Sum of Squares

For simplicity, prior analyses in this project used Type-1 sum of squares. Dependency on the order of model terms and balanced data in Type-I sum of squares was unwanted in this exploratory stage of understanding this dataset. Additionally, considering the unbalanced nature of the data, it was decided that Type-I sum of squares should not be used in this phase of the analysis. The consulted literature did not indicate strong motive to choose the more complicated (Langsrud, 2003), and somewhat more controversial (Hector, von Felten, & Schmid, 2010), Type-III sum of squares approach. Furthermore, given the minimal effect on the significance of the interaction terms, the impact of this choice was considered small in the overall development of the analysis method.

5.1.4 Comparisons using the Tukey Honest Significant Differences Method

Similar to the original analysis of the Dark Brown soil zone dataset, Tukey HSD comparisons were used to compare the levels of the factors involved in the model that affected the yield. The Tukey HSD method was selected due to its inherent ability to adjust for multiple comparisons. Both main effects and interactions can be compared with this method.

One computation of all possible interactions within each model is required; however, only some groupings of interactions were of interest, so only those comparisons are reported. Specifically, the *impactcode:w_class* interaction was significant in both models, but only comparisons within the same wetland class are discussed further. Similarly, comparisons for the *impactcode:crop* interaction within the same crop type were reported. The Tukey results are identified using letters to differentiate the groupings. Data are considered statistically equal if it shares a letter with another data point; data that do not share a letter are not considered statistically equal. The significance level for this data was also based on a p-value of 0.05. All yield data compared in the results are based on yield data as a percentage of the field average. Therefore, “100%” in the data represents the field average.

5.2 Statistical Analysis of Dark Brown Soil Zone Dataset

The following subsections provide the statistical analysis of the Dark Brown soil zone data that was collected for this study.

5.2.1 Statistical Analysis Procedure

Within RStudio, a methodology that was nearly identical to that used for the Black soil zone data was repeated when analyzing the Dark Brown soil zone dataset. The method only deviated from the procedure given in **Section 4.1** due to the terms that were not found to be significant. 463 records were removed due to yield values above 200% of field average. A further 7,439 records were filtered from the original dataset based on crop type. 30,151 records were used in the statistical analysis.

Similar to the analysis of the Black soil zone data, type-II sum of squares were used during ANOVA calculations, and the Tukey HSD test was used for comparisons; see **Sections 5.1.3** and **5.1.4**, respectively, for further explanations.

5.2.2 Statistical Model Forms

Data were again split between being in the wetland (buffer distance = 0 m), and in the buffer zone (buffer distance >= 5 m). The final model form for the data in the wetland (0-meter buffer zone, with impact codes 0 and 1 removed) was:

yield_as_percent_of_field ~ crop + w_class+ year + field

All interaction terms were not found to be significant. The results of an ANOVA of that model are given in **Table 10**.

Table 10. ANOVA results of statistically significant variables of total yield (as a percentage of field average) in the wetland only (0 m buffer).

Response:	**Yield as a percentage of Field Average**			
	Sum Sq	**DF**	**F value**	**P-value**
wetland class	59252	3	11.63	0.0000
year	408777	3	80.26	0.0000
crop	54877	3	10.77	0.0000
field	80728	19	2.50	0.0003
Residuals	3061178	1803		

The final model form fit to the data in the buffer zone (5-50-meter buffer zone) was:

yield_as_percent_of_field ~ (impactcode + crop + w_class+ year + d_buffer)^2
+ d_buffer:field – w_class:d_buffer - year:crop + field

In contrast to the model in the buffer zone from the Black soil zone data, the interaction *d_buffer:impactcode* was found to be significant, and the interaction *w_class:d_buffer* was not found to be significant. The results of the ANOVA are given in **Table 11**.

Table 11. ANOVA results of statistically significant variables of total yield (as a percentage of field average) in the buffer zone only (5-50 m).

Response:	**Yield as a percentage of Field Average**			
	Sum Sq	**DF**	**F value**	**P-value**
impact code	699058	3	255.50	0.0000
crop	120979	3	44.22	0.0000
wetland class	489951	3	179.08	0.0000
year	150218	3	54.90	0.0000
buffer	316911	9	38.61	0.0000
field	411516	19	23.75	0.0000
impact code : crop	83557	9	10.18	0.0000
impact code : wetland class	40142	9	4.89	0.0000
impact code : year	103976	9	12.67	0.0000
impact code : buffer	69917	27	2.84	0.0000
crop : wetland class	53360	9	6.50	0.0000
crop : buffer	40879	27	1.66	0.0170
wetland class : year	85042	9	10.36	0.0000
year : buffer	369863	27	15.02	0.0000
buffer : field	184925	171	1.19	0.0493
Residuals	25120904	27545		

6. Black Soil Zone Dataset Agronomic Analysis Results

The comparisons in this section include the yield (as a percentage of the field average) as a function of the significant variables as well as the significant interactions between the variables previously described. The wetland data (0-meter buffer) includes all data from only buffer zone 0, and impact codes farmed (2) and completely drained (5). Impact codes intact (0) and partially drained (1) are not included in the wetland data as these impact codes theoretically should not have yield data due to these areas not being cropped. However, all impact codes are accounted for in the buffer analysis (5-50-meter buffer).

6.1 Single Comparisons

The single comparisons reviewed yield (as a percentage of the field average) by single variables in the data including impact code, wetland class, crop type, year, field, and buffer zone. The results included in this section highlight the significant variables.

6.1.1 Single Comparisons in the Wetland (0-meter buffer)

The single interactions found to be significant in the wetland (buffer zone 0-meters only) included the following:

- Impact code
- Wetland class
- Year
- Crop type
- Field

The impact code results showed that the completely drained (5) wetlands yielded significantly higher (by 9.1%) compared to the farmed (2) wetlands (**Table 12**). This indicates that in this dataset (for the wetland only), there is significant benefit to completely draining the wetland.

Table 12. Yield (as a percentage of field average) and Tukey groupings of wetland data (0-meter buffer zone only) by impact code.

Impact Code	2	5
Yield/ Tukey Grouping	74.2 a	83.3 b

When reviewing yield in the wetland by wetland class, temporary wetlands (2) yielded significantly higher than the remaining wetland classes by at least 12.6% and up to 28.8%. This was followed by semi-permanent wetlands (4), seasonal wetlands (3), and permanent wetlands (5), which yielded the lowest. The greatest spread in yield data shows that temporary wetlands (2) yielded 28.8% higher than permanent wetlands (5) (**Table 13**).

Table 13. Yield (as a percentage of field average) and Tukey groupings of wetland data (0-meter buffer zone only) by wetland class.

Wetland Class	2	3	4	5
Yield/ Tukey Grouping	81.0 a	65.1 b	68.4 b	52.2 c

Year-by-year comparisons showed varying levels of significance. When reviewing the precipitation averages in **Table 3** and **Table 4**, there is a large variance in total precipitation across the years. Annual differences can likely be explained by environmental conditions, and the data showed yield differences up to 43.8% across the seven years. The greatest difference existed between 2015 and 2020, with 2020 showing a significantly higher yield. These yield averages are further deconstructed in **Appendix C**.

There were significant differences noted between crop type. Different crops have different levels of tolerance when considering moisture level variations, topography, soil characteristics, and overall management. The data showed that yellow peas yielded significantly lower than barley, canola, and wheat, with yields ranging from 16% to 25%, respectively. Agronomically speaking, this is reasonable, as dry peas do not tolerate either water-saturated or salt-affected soils, both of which are common in wetlands, whereas wheat, canola, and barley have moderate tolerances to saline areas (with barley allowing for the highest tolerances between the three) (Agriculture and Agri-Food Canada, 2009). Differences in crop response by field can be due to a variety of reasons, such as wetland characteristics in field, topography, soil characteristics, weather patterns, historical field management, etc. **Appendix C** highlights the Tukey differences between the crop types as well as the averages of the fields.

Similar to crop type, there were differences found between the fields in the dataset. This could be due to soil quality and characteristics, topography, pest pressure, salinity, and other variables that cause certain fields to out-perform others. These averages can be found in **Appendix C**.

6.1.2 Single Comparisons in the Buffer (5-50-meter buffer)

The single interactions found to be significant in the buffer (5-50 meters) included the following:

- Impact code
- Wetland class
- Year
- Buffer zone
- Crop type
- Field

The significant differences found in the impact code data show that farmed (2) wetlands yield significantly higher than completely drained (5) wetlands, partially drained (1), and intact wetlands (0), respectively, with a yield difference as great as 20.1% between the intact (0) and farmed (2) wetlands (**Table 14**). This displays that on average, in the 5-50-meter buffer area surrounding impact code 0 and 1 wetlands, a significantly higher yield can be expected by completely draining wetlands compared to either partially draining or leaving wetlands intact (not draining at all). Yield was significantly higher in the 5-50 meter buffer zone by 18.9% for impact code 5 versus impact code 0 and by 16.5% for impact code 5 versus impact code 1.

Table 14. Yield (as a percentage of field average) and Tukey groupings of buffer zones 5-50 by impact code.

Impact Code	0	1	2	5
Yield/ Tukey Grouping	77.4 a	79.8 b	97.5 c	96.3 d

Wetland class differences followed a similar trend in the 5-50-meter buffer zone as the wetland (0-meter) data, where the temporary wetlands (2) had significantly higher yields than the remaining wetland classes. This is followed by semi-permanent (4), seasonal (3), and permanent (5) wetlands, respectively, with yield differences as great as 28.7% between the temporary (2) and permanent (5) wetlands (**Table 15**). This indicates that on average, the temporary wetlands (2) yield at almost field average, whereas the wetlands with greater water contents yield significantly lower (as low as 69.0% of field average).

Table 15. Yield (as a percentage of field average) and Tukey groupings of buffer zones 5-50 by wetland class.

Wetland Class	2	3	4	5
Yield/ Tukey Grouping	97.7 a	86.1 b	80.6 c	69.0 d

Some significant annual differences were also noted in the data. Again, this can be attributed to the environmental conditions experienced in each year. The average yield differences, similar to the wetland data (0-meter), display that the most recent years show significantly higher yields than earlier years (with differences up to 11.7%). With recent years receiving less average precipitation, or lack thereof at undesirable times during the growing season, the data shows that these wetland areas likely held enough water to supply adequate moisture for the greater yield values (**Table 3** and **Table 4**). The averages and Tukey groupings can be found in **Appendix C.**

The 5–50-meter buffer zone showed varying significant yield differences across zones. The yield at the buffer closest to the wetland (5-meter buffer zone) is approximately 13% lower than the yield 50 meter away from the wetland, where the 50-meter yield value is close to field average (field average being 100%). This indicates that there is little reason to expand the buffer zones further into the field for wetland impacts beyond the 50 meters. Though there were varying levels of significance, the data shows that on average across the seven years of data, the closer to the wetland, the lower the average yield (**Figure 5**). The Tukey groupings of the buffer zones can be found in **Appendix C**.

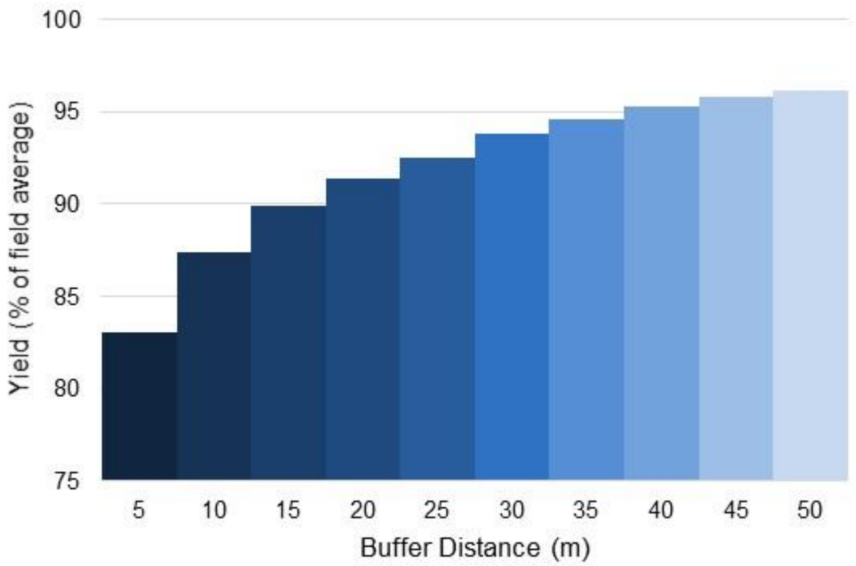

Figure 7. Yield (as a percentage of field average) of buffer zones 5 to 50, Black soil zone dataset.

Crop type was also found to be significant in the buffer data. Overall, peas again yielded significantly the lowest across the four crop types, with canola and wheat yielding statistically the same and the highest. These results along with the averages by the variable “field” can be found in **Appendix C**, which also displayed some expected significant differences.

6.2 Two-way Interactions

This section encompasses the significant two-way interactions found between the single variables discussed in **Section 6.1.2**.

6.2.1 Two-way Interactions in the Wetland (0-meter buffer)

The two-way interactions found to be significant in the wetland (in 0-meter buffer zone only) include the following:

- Wetland class: impact code
- Impact code: crop type
- Impact code: year

Yield comparisons of wetland class, by impact code, display some significant differences in the wetland (0-meter buffer) for the impact codes farmed (2), and completely drained (5) wetlands (**Table 16**). Though only significant in wetland classes 2 and 3 (temporary and seasonal wetlands), completely drained wetlands (5), on average, had higher yields than farmed wetlands with the exception of wetland class 5 (permanent wetlands), which showed a trend of farmed wetlands yielding higher, though this was not considered significant. The temporary and seasonal wetlands showed differences in yield responses of 10.7% and 22.3% between farmed and completely drained wetland yields, respectively, with the greatest response seen in the seasonal wetlands.

Table 16. Yield (as a percentage of field average) and Tukey groupings of wetland data (0-meter buffer zone only) by wetland class, by impact code for the Black soil zone dataset.

Wetland Class	**Temporary (2)**		**Seasonal (3)**		**Semi-permanent (4)**		**Permanent (5)**	
Impact Code	**2**	**5**	**2**	**5**	**2**	**5**	**2**	**5**
Yield/Tukey Grouping	77.9 a	88.6 b	53.9 a	76.2 b	53.0 a	76.0 a	58.3 a	51.6 a

Impact code by crop type displayed significant differences for canola and wheat yield. The completely drained (5) wetlands yielded approximately 12% higher than farmed (2) wetlands for canola, and approximately 13% higher for wheat. Data for the yellow peas and barley displayed no significant differences (**Table 17**). This crop response shows that completely drained (5) wetlands have a significant effect, resulting in higher yields for canola and wheat. However, for peas, there was no significant difference between farmed (2) and completely drained (5) impact codes; the yield response is agronomically quite low compared to the other crops, indicating the sensitivity of the crop in general.

Table 17. Yield (as a percentage of field average) and Tukey groupings of wetland data (0-meter buffer zone only) by crop type, by impact code for the Black soil zone dataset.

Crop	**Barley**		**Canola**		**Peas**		**Wheat**	
Impact Code	**2**	**5**	**2**	**5**	**2**	**5**	**2**	**5**
Yield/ Tukey Grouping	75.9 a	71.1 a	71.5 a	83.1 b	65.2 a	50.5 a	79.2 a	91.9 b

Impact code by year showed some differences (highlighted in **Appendix C**). In all years, with the exception of 2015, the yield averaged higher for completely drained (5) versus farmed (2) wetlands with overall averages greater in 2019 and 2020 when compared to previous years. This pattern has been apparent in previous data as well and displays that, on average across the entire data set by year, completely drained (5) wetlands yield higher than farmed (2) wetlands. Though no Tukey analysis was completed on this dataset, the trend is important to note.

6.2.2 Two-way Interactions in the Buffer (5-50-meter buffer)

Though this section will only highlight some key interactions, all two-way interactions found to be significant in the wetland (5-50-meter buffer) included the following:

- Impact code: wetland class
- Impact code: crop type
- Buffer zone: year
- Impact code: year
- Buffer zone: crop type
- Wetland class: crop type
- Buffer zone: wetland class

- Wetland class: year
- Buffer zone: field

Yield comparisons of wetland class by impact code show that completely drained wetlands (impact code 5) yielded significantly higher than the other impact codes in most scenarios (**Table 18**). Temporary (2), seasonal (3), and semi-permanent (5) wetlands all indicate a greater yield when the wetland is completely drained. Impact code results in permanent wetlands showing varying averages, all of which trended lower than the other wetland classes, with intact (impact code 0) wetlands yielding the lowest by a significant margin. These differences are greater seen in **Figure 6**.

Table 18. Yield (as a percentage of field average) and Tukey groupings of buffer data (5-50-meter buffer zones) by wetland class, by impact code, in the Black soil zone dataset.

Wetland Class	Impact Code	Yield	Tukey Grouping
Temporary (2)	0	83.8	a
	1	67.8	b
	2	99.2	c
	5	99.2	c
Seasonal (3)	0	78.3	a
	1	88.4	b
	2	89.0	b
	5	94.5	c
Semi-permanent (4)	0	74.1	a
	1	79.6	b
	2	85.0	b
	5	92.7	c
Permanent (5)	0	67.3	a
	1	78.0	b
	2	72.7	ab
	5	68.2	b

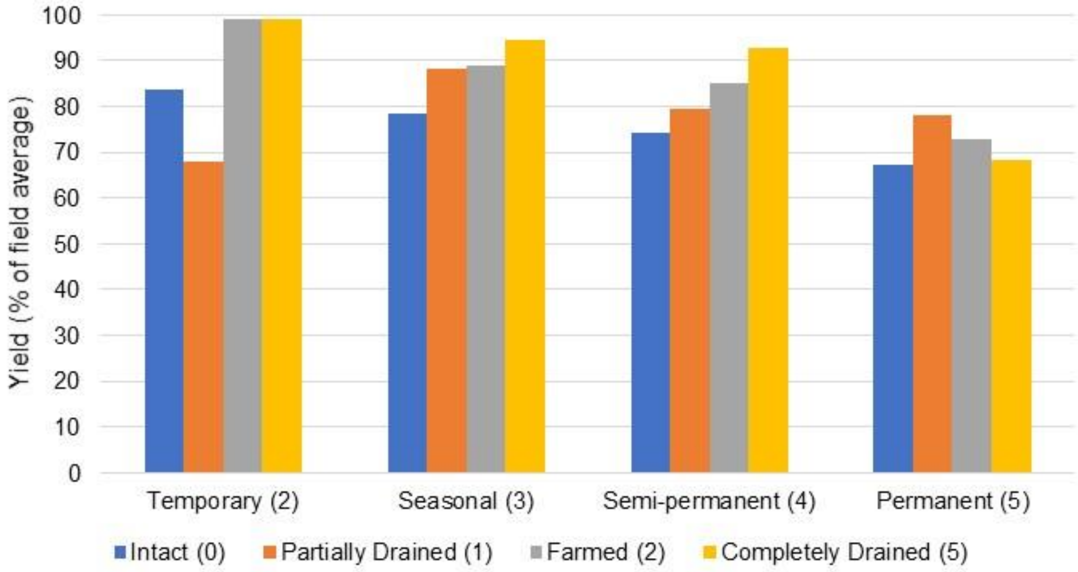

Figure 8. Yield (as a percentage of field average) by impact code, by wetland class in the 5–50-meter buffer zone, for the Black soil zone dataset.

The crop response by impact code of the four studied crops (barley, canola, peas, and wheat) are displayed in **Table 19**, and **Figure 7**. For canola and yellow peas, the average yield showed significantly lower in intact wetlands (0), except for wheat, where partially drained (1) yielded statistically the same as intact (0). This was also different in the barley data where partially drained (1) wetlands yielded the lowest by a significant margin. This illustrates that on average in the 5-50-meter buffer zone, each crop type is negatively impacted by intact (0) wetlands and partially drained (1) wetlands compared to the field average by producing >82.4% of the field average (as low as 51.1% for peas). For barley and peas, farmed (2) wetlands yielded significantly higher than all other wetland classes, whereas farmed (2) and completely drained (5) wetlands yielded statistically the same for canola and wheat, though higher than the remaining impact codes. These results indicate that overall, farmed (2) or completely drained (5) wetlands yield significantly higher than intact (0) and partially drained (1) wetlands for all crop types in this dataset, with differences as high as 22.8% for barley, 20.1% for canola, 48.4% for peas, and 22.6% for wheat.

Table 19. Yield (percent of field average) of crop type by impact code, in the 5-50-meter buffer zone, for the Black soil zone dataset.

Crop	Impact Code	Yield	Tukey Grouping
Barley	0	79.6	a
	1	72.7	b
	2	95.5	c
	5	92.8	d
Canola	0	77.9	a
	1	82.4	b
	2	98.0	c
	5	97.5	c
Peas	0	51.1	a
	1	70.6	b
	2	94.9	c
	5	85.7	b
Wheat	0	77.7	a
	1	75.4	a
	2	98.0	b
	5	96.7	b

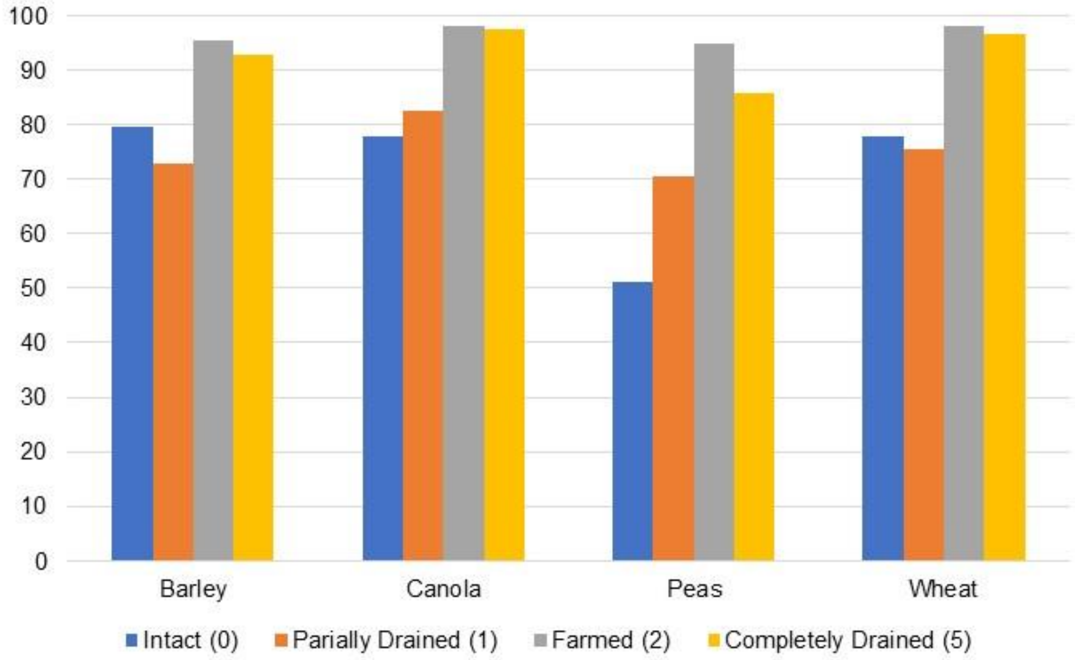

Figure 9. Yield (as a percentage of field average) by impact code, by crop type in the 5-50-meter buffer zone, for the Black soil zone dataset.

The buffer zone yield averages including the wetland (0-meter buffer) and the buffer zone (5-50 meters) by year display a noteworthy pattern. On average, as previously mentioned, the further from the wetland, the closer the yield value returns to field average. Years 2014 to 2018 inclusively display the same pattern; that is, low yield (as low as 53%) of the field average in the wetland, which increases up to 97% at the 50-meter buffer. However, for years 2019 and 2020, the wetland average displays high and relatively consistently similar yields to the 5-50-meter buffer zones. It must be noted again that the 0-meter buffer (wetland) only displays the farmed (2) and completely drained (5) wetlands. The average yield in the wetland to the remaining buffer zone averages by year is displayed in **Figure 8**, and further detailed in **Appendix C.**

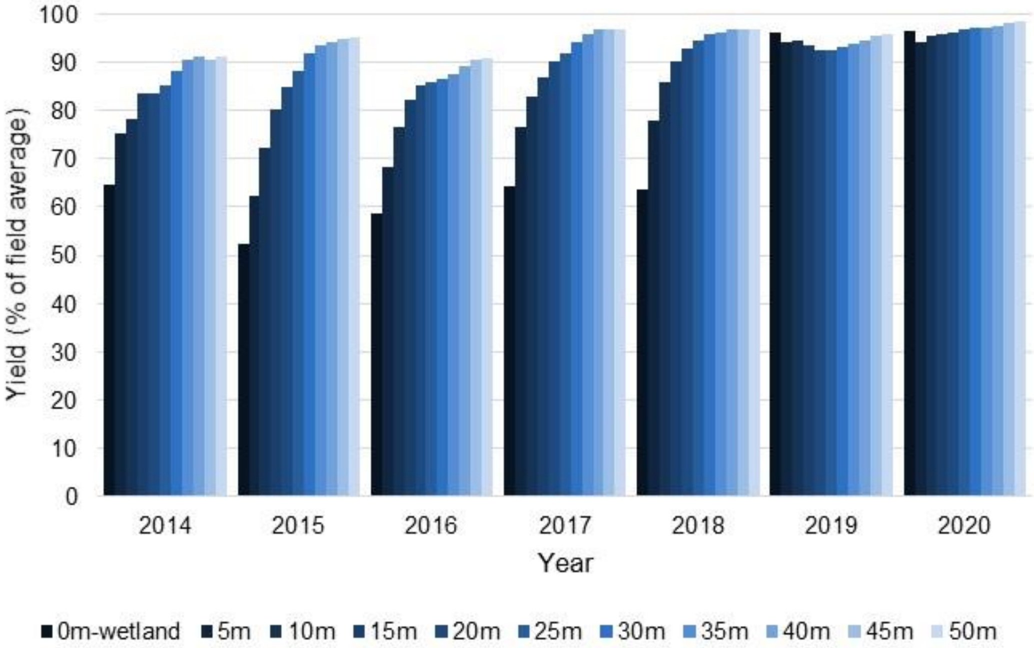

Figure 10. Average yield (as a percentage of field average) by buffer zone, by year for all Black soil zone data.

The remaining significant interaction comparisons were not analyzed through a Tukey analysis; however, the averages can be found in **Appendix C**. The trends found in these interactions were comparable to those previously discussed in this section.

7. Dark Brown Soil Zone Dataset Agronomic Analysis Results

Like the analysis conducted for the Black soil zone, this section includes significant variables and significant interactions between the variables compared to yield (as a percentage of the field average). The data is again split into two sections: in the wetland (0-meter buffer), and the buffer (5-50-meter buffer).

7.1 Single Comparisons

The single comparisons reviewed yield (as a percentage of the field average) by single variables in the data including impact code, wetland class, crop type, year, field, and buffer zone. The results included in this section highlight the variables that were significant.

7.1.1 Single Comparisons in the Wetland (0-meter buffer)

The single interactions found to be significant in the wetland (buffer zone 0-meters only) included:

- Wetland class
- Year
- Crop type
- Field

Unexpectedly, impact code did not show any significance in the wetland in this dataset, indicating that whether the wetland was drained or undrained, the yield was statistically the same whether it was farmed or completely drained for this dataset.

When the data was analyzed by wetland class, there were few significant differences found. As displayed in **Table 20**, temporary wetlands (2) yield statistically the same as permanent wetlands (5), and seasonal (3), semi-permanent (4), and permanent (5) wetlands all yield statistically the same. The greatest differences noted are that temporary wetlands (2) yielded up to 10.2% higher than seasonal wetlands (3), and 30.6% higher than semi-permanent wetlands.

Table 20. Yield (as a percentage of field average) and Tukey groupings of wetland data (0-meter buffer zone only) by wetland class.

Wetland Class	2	3	4	5
Yield/ Tukey Grouping	109 a	98.8 b	78.4 b	72.2 ab

The year-by-year comparisons of the data across the four years showed some significant differences of average yield, with the greatest difference seen between 2016 and 2018, where 2018 yielded approximately 66.1% higher than 2016. These averages can be seen in **Appendix C**. Reviewing the precipitation data in **Table 5**, the precipitation in 2016 was near double the 2018 precipitation (445 mm versus 226 mm). Due to this precipitation, the wetlands could have been drowned out and unable to produce adequate crop growth, resulting in the significantly lower yield. The 2019 data displayed statistically the same yield as 2018, though the data differed by about 120mm more precipitation in 2019 than 2018. Though there was more total rain in 2019, the data shows that the month of May was very dry which likely caused some emergence issues, potentially affecting the final yield (**Table 6**).

Crop response for each of the four crops across all data displayed few significant differences, with the only significant yield difference being between yellow peas and canola, where the yellow peas yielded slightly higher than the canola, though the means only displayed a <1% difference. Crop response differences are expected due to different agronomic crop needs and management. These averages can be found in **Appendix C**.

The final single significant variable in the wetland (0-meter buffer) was field. As expected, there were some significant differences found between the field averages which can be due to many variables, as discussed above in the results from the Black soil zone dataset. The field differences are also highlighted in **Appendix C**.

7.1.2 Single Comparisons in the Buffer (5-50-meter buffer)

The single interactions found to be significant in the buffer (5-50 meters) were the same variables found to be significant in the Black soil zone dataset, and included:

- Impact code
- Wetland class
- Year
- Buffer zone
- Crop type
- Field

The significant differences found in the impact code data show that in the 5-50-meter wetland buffer zone, farmed (2) and completely drained (5) wetlands yield significantly higher than intact (0) and partially drained (1) wetlands with a difference as great as 29.6% between farmed (2) and partially drained (1) wetlands. Yield was significantly higher in the 5-50 meter buffer zone by 11.8% for impact code 5 versus impact code 0 and by 24.9% for impact code 5 versus impact code 1. This trend was also noted in the Black soil zone data. **Table 21** displays the averages and Tukey groupings. These results indicate that, as also seen in the Black soil zone dataset, a greater yield response can be expected for this dataset in the buffer zone for wetlands that are either farmed or completely drained.

Table 21. Yield (as a percentage of field average) and Tukey groupings of buffer zones 5-50 by impact code.

Impact Code	0	1	2	5
Yield/ Tukey Grouping	83.2 a	70.1 b	99.7 c	95 d

Wetland class differences displayed the greatest difference in yield between temporary (2) yielding up to 30.0% greater than permanent (5) wetlands. Each wetland class yielded significantly different from one another, with temporary (2) yielding highest, followed by seasonal (3), semi-permanent (4), and permanent (5) wetlands which yielded significantly lower than the other wetland classes (**Table 22**). This trend was also found in the Black soil zone dataset when reviewing yield by wetland class in the 5-50-meter buffer. As seen in the table, temporary wetlands yielded at field average whereas permanent wetlands only yielded at 70% of the field average.

Table 22. Yield (as a percentage of field average) and Tukey groupings of buffer zones 5-50 by wetland class.

Wetland Class	2	3	4	5
Yield/ Tukey Grouping	100 a	87.2 b	74.6 c	70.0 d

Yearly differences displayed some significance across the four years of data with the greatest difference in yield (between 2016 and 2018) of approximately 10.9%. As highlighted in Section 3.0 (**Tables 5 and 6**), 2016 had the greatest total precipitation across the four years, which may have been the reason for the significantly lower yield. These averages and Tukey groupings can be found in **Appendix C**.

The buffer zone yields displayed some significant differences from the 5-meter to the 50-meter buffer, as displayed in **Figure 9**, with the averages and Tukey groupings located in **Appendix C**. This dataset displays an interesting trend where the yield significantly dips towards the 25-meter buffer zone, and gradually increases from there. This trend displays a common condition found in Prairie soils, where a salinity ring (“bathtub ring”) may be causing the decrease in yield, caused by wetlands expanding in wet years and depositing salts as they recede in the drier years. In this dataset, the 5-meter buffer displayed the highest yield (significantly) compared to the remaining buffer zones. On average, this trend was different from the trend found in the Black soil zone dataset where the 5-meter buffer zone displayed the lowest yield, which gradually increased to approximate field average at the 50-meter buffer zone.

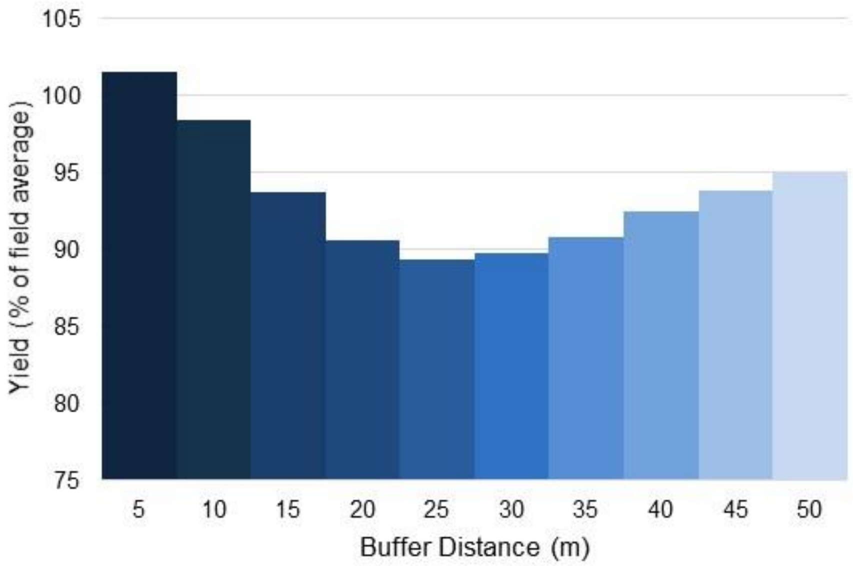

Figure 11. Yield (as a percentage of field average) of buffer zones 5-50, Dark Brown soil zone dataset.

The crop response showed significant differences across the four crop types studied, with canola showing the greatest crop yield response (at 97.7%), and peas showing the lowest crop yield response (87.4%). These averages and Tukey groupings can be seen in **Appendix C**.

Field again showed significant differences (as expected), and the averages are highlighted in **Appendix C**.

7.2 Two-way Interactions

In this dataset, there were only significant interactions found in the buffer zone area (5-50-meter buffer), and no significant interactions were found in the wetland only data (0-meter buffer).

7.2.1 Two-way Interactions in the buffer (5-50-meter buffer)

The two-way interactions found to be significant in the buffer zone (5-50-meter buffer) included:

- Impact code: wetland class
- Impact code: crop type
- Buffer zone: year
- Impact code: year
- Buffer zone: crop type
- Wetland class: crop type
- Impact code: buffer zone

- Wetland class: year
- Buffer zone: field

These significant interactions were also found in the Black soil zone as previously mentioned, with exception of impact code: buffer zone was significant in this dataset and not in the Black soil zone dataset, and buffer zone: wetland class was significant in the Black soil zone dataset, and not this dataset. This section will only highlight a few key interactions, with the remaining data located in **Appendix C**.

Comparing wetland class by impact code data, wetlands that were farmed (2) or completely drained (5) in temporary (2) and seasonal (3) wetlands, yielded significantly higher than intact (0) and partially drained (1) wetlands by a difference of up to 26% (**Table 23**). Semi-permanent (4) and permanent (5) wetlands however displayed significantly highest yields in intact wetlands (impact code 0). This indicates that in this dataset, yields are greater for farmed and completely drained wetlands in wetland classes 2 and 3 (temporary and seasonal), whereas undrained wetlands in wetland classes 4 and 5 (semi-permanent and permanent) yield the greatest. These differences are also highlighted in **Figure 10**. It should be noted that, although statistically different groupings were found in the analysis, the limited number of data points available for wetland classes 4 and 5 (semi-permanent and permanent, 1889 and 590 points, respectively) introduce a large uncertainty in the above interpretation. This is in addition to the limited agronomic difference between these wetland classes.

Table 23. Yield (as a percentage of field average) and Tukey groupings of buffer data (5-50-meter buffer zones) by wetland class, by impact code, in the Dark Brown soil zone dataset.

Wetland Class	Impact Code	Yield	Tukey Grouping
Temporary (2)	0	95.7	a
	1	75.3	b
	2	101	c
	5	98.7	c
Seasonal (3)	0	82.9	a
	1	70.4	b
	2	94.4	c
	5	92.4	c
Semi-permanent (4)	0	77.1	a
	1	68.1	b
	2	71.8	b
	5	77.0	b
Permanent (5)	0	74.9	a
	1	58.2	b
	2	57.3	b
	5	63.6	b

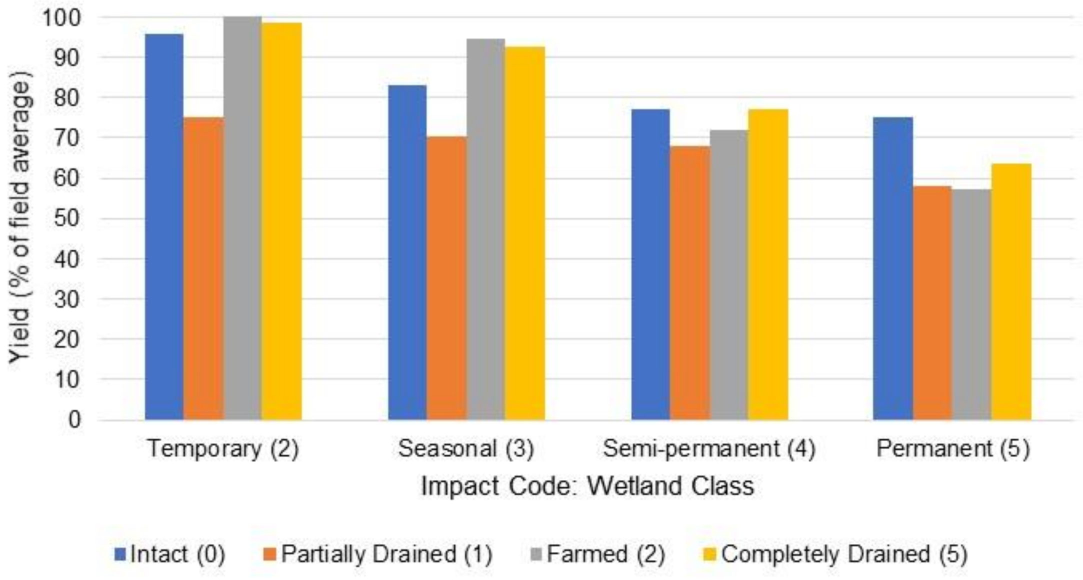

Figure 12. Yield (as a percentage of field average) by impact code, by wetland class in the 5-50-meter buffer zone, in the Dark Brown soil zone dataset.

The crop response by impact code for barley, canola, peas, and wheat are provided in **Table 24**, and **Figure 11**. For each of the crop types, the yield responses displayed significantly higher yields in the farmed (2) and completely drained (5) wetlands compared to the intact (0) and partially drained (1) wetlands. The crop responses varied by crop but showed the greatest difference in yield for the canola where the farmed (2) and completely drained (5) wetlands yielded up to 26.5% higher than the intact (0) and partially drained (1).

Table 24. Yield (percentage of field average) of crop type by impact code, in the 5-50-meter buffer zone, in the Dark Brown soil zone dataset.

Crop	Impact Code	Yield	Tukey Grouping
Barley	0	89.6	a
	1	72.0	b
	2	98.9	c
	5	95.1	c
Canola	0	82.1	a
	1	77.5	a
	2	104	b
	5	102	b
Peas	0	79.6	a
	1	57.3	b
	2	95.3	c
	5	89.0	d
Wheat	0	82.9	a
	1	70.5	b

	2	98.5	c
	5	93.9	d

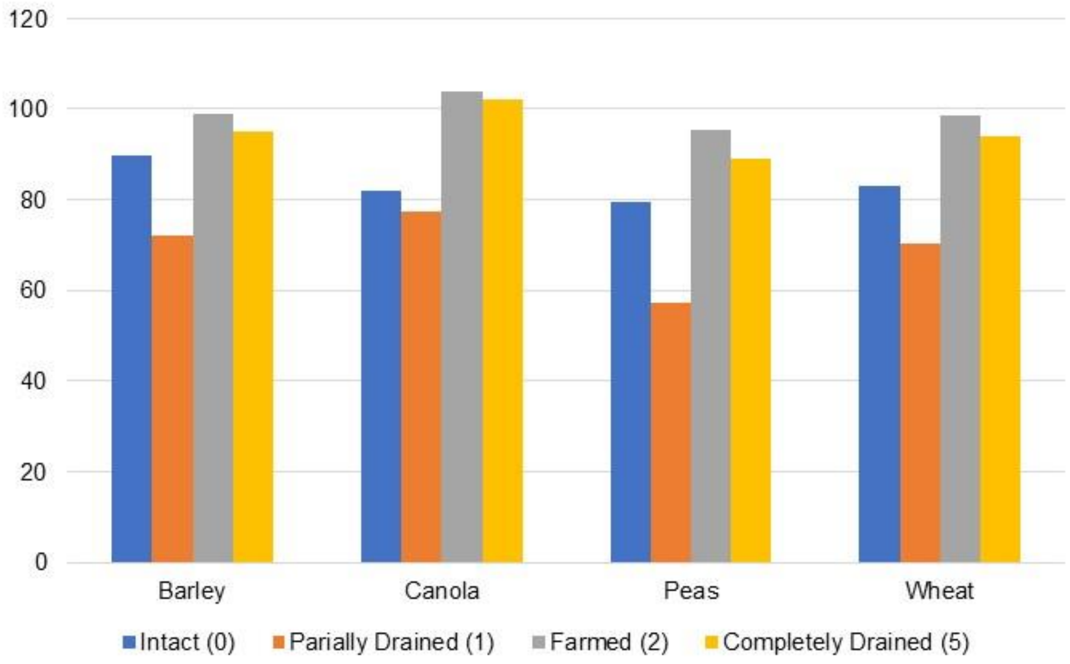

Figure 13. Yield (as a perfect of field average) by impact code, by crop type in the 5-50-meter buffer zone, in the Dark Brown soil zone dataset.

The buffer zone yield averages, including the 0-meter buffer (the wetland itself) by year can be seen in **Figure 12**. However, 2016 showed the opposite trend when compared to 2017, 2018, and 2019 with the wetland yielding the lowest, which then incrementally increases until the 50-meter buffer. Reviewing the precipitation data (**Table 5** and **Table 6**), 2016 had the highest total precipitation compared to the following three years, which may have resulted in poorer yields in the wetland due to excess moisture. The following years (2017, 2018, and 2019) display similar trends where the wetland itself had a high yield, which dipped down around the 20-25-meter buffer where it began to increase again. As previously described, this could be due to the salinity ring ("bathtub ring") that can form around wetlands. These averages are located in **Appendix C**.

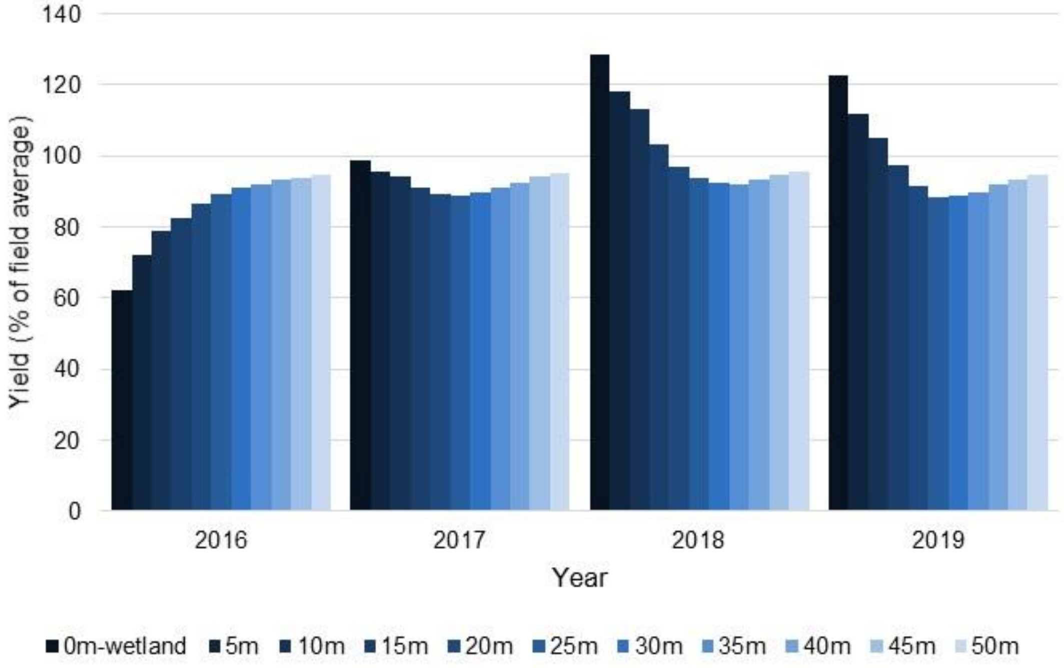

Figure 14. Average yield (as a percentage of field average) by buffer zone, by year for all Dark Brown soil zone dataset.

The remaining significant interaction averages can be found in **Appendix C**. These interactions were not analyzed through a Tukey comparison test; however, the trends in the averages display similarly to the data previously discussed.

8. Economic Results and Discussion

8.1 Initial Calculations

The initial analysis completed was to establish the cost benefit relationship to drainage is addressed within the following subsections. The mitigation scenario is a review of the data as collected and includes areas of intact wetlands, wetlands drained, partially drained, and farmed but not drained (largely Class I and II wetlands). The fully drained and no drainage scenarios are simulations based on the data as collected. A fully drained scenario was simulated by driving the intact wetland and buffer areas with data from the fully drained wetland and buffer zones. A no-drain scenario was simulated by driving the fully drained zones with data from the intact wetlands and buffer zones. The fully drained scenario assumes all of the wetlands in the study are drained with the exception of impact code 2 (undrained but farmed) wetlands. The no drainage-scenario assumes all wetlands are undrained.

8.1.1 Crop Yield Benefits and Costs

The crop yield benefits, and input costs are unique for the Dark Brown or Black soil zone Economic Models as defined in the Saskatchewan Crop Planning Guide 2022. The calculations from the guide are based on the inputs and returns associated with attaining a target yield in the 80th percentile for each soil zone. The details of the agronomic assumptions are located in **Appendix F**. The data used in the two studies is summarized in **Table 25** and **Table 26**.

Table 25. Crop benefits for Dark Brown soil zone: (Government of Saskatchewan, 2022).

	Spring Wheat	Canola	Yellow Peas
Target Yield (kg/ha)	3,855	2,644	3,237
Farm gate ($/t)	$387.97	$750.00	$440.88
Crop Prod. Guide Baseline($/ha)	$1,495.73	$1,983.10	$1,427.18

Table 26. Crop benefits for Black soil zone: (Government of Saskatchewan, 2022).

	Spring Wheat	Canola	Yellow Peas	Malt Barley
Target Yield (kg/ha)	4325	2867	3707	3967
Farm gate ($/t)	$387.97	$750.00	$440.88	$280.63
Crop Prod. Guide Baseline($/ha)	$1,677.86	$2,149.97	$1,634.45	$1,113.18

The economic models are based on an equal area rotation of the crop types listed.

Table 27. Crop production costs for Dark Brown soil zone economic model (Government of Saskatchewan, 2022).

	Spring Wheat	Canola	Yellow Peas
Seed	$26.92	$75.73	$63.20
Seed Treatments/Inoculants	$0.74	$9.00	$10.93
Fertilizer -Nitrogen	$126.50	$133.16	$10.39
-Phosphorous (P2O5)	$31.55	$46.04	$31.55
-Sulphur and Other	$0.00	$8.42	$0.00
Plant Protection -Herbicides	$59.95	$58.24	$66.08
-Insecticides	$21.89	$2.46	$15.22
-Fungicides	$19.35	$14.18	$14.18
Machinery Operating -Fuel	$15.31	$16.21	$17.12
-Repair	$9.98	$9.98	$9.98
Custom Work and Hired Labour	$22.05	$21.05	$20.30
Crop Insurance Premium	$4.59	$10.51	$5.14
Hail Insurance Premium	$12.25	$12.25	$12.25
Utilities and Miscellaneous	$4.23	$4.23	$4.23
Interest on Variable Expenses	$7.13	$8.46	$5.63
Other (buildings, property, machinery)	$107.53	$107.53	$107.53
Total ($/ac)	$469.96	$537.45	$393.71

Table 28. Crop production costs for Black soil zone economic model: Saskatchewan Crop Planning Guide 2022.

	Spring Wheat	Canola	Yellow Peas	Malt Barley
Seed	$30.60	$75.73	$71.20	$40.61
Seed Treatments/Inoculants	$0.84	$9.00	$12.31	$1.02
Fertilizer -Nitrogen	$141.15	$143.81	$11.85	$103.86
-Phosphorous (P2O5)	$35.81	$49.45	$35.81	$28.99
-Sulphur and Other	$0.00	$9.21	$0.00	$0.00
Plant Protection -Herbicides	$63.33	$66.28	$72.41	$63.78
-Insecticides	$21.89	$2.46	$15.22	$21.89
-Fungicides	$19.35	$14.18	$14.18	$19.35
Machinery Operating -Fuel	$19.14	$20.27	$21.39	$19.14
-Repair	$11.29	$11.29	$11.29	$11.29
Custom Work and Hired Labour	$23.05	$21.05	$20.30	$21.05
Crop Insurance Premium	$4.78	$10.96	$6.01	$4.68
Hail Insurance Premium	$12.25	$12.25	$12.25	$12.25
Utilities and Miscellaneous	$4.88	$4.88	$4.88	$4.88
Interest on Variable Expenses	$7.79	$9.05	$6.20	$7.08
Other (buildings, property, machinery)	$116.87	$116.87	$116.87	$116.87
Total ($/ac)	$513.02	$576.74	$432.18	$476.75

8.1.2 Drainage Excavation

The Client provided a preliminary estimate of the cost of wetland drainage for this economic model based on the following analysis. The volume of soil material removed to construct drainage ditches was determined for 17 quarter sections in the Dark Brown soil zone data set at Arm River Farms. Cross sections of ditch segments were derived from a digital elevation model (DEM) of LiDAR data. **Figure 15** is an example of a quarter section showing the ditch segments in orange and the ditch cross section locations as black lines numbered at one end from 0 to 12.

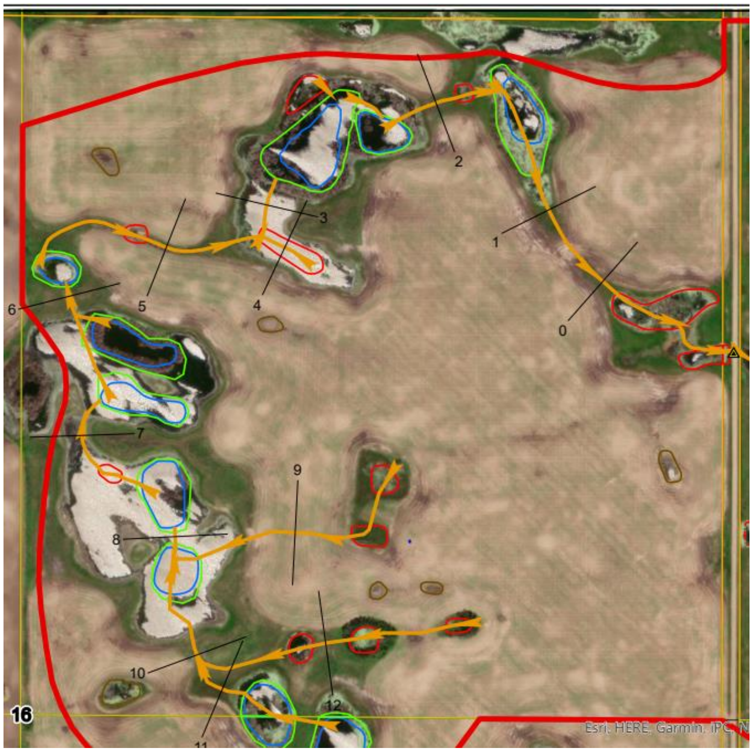

Figure 15. Field Drain Cross Section Measurement Locations.

The cross-sectional area of the ditch and ditch length were used to calculate the volume of excavation for each ditch segment. A total of 148 individual ditch segments were investigated. An example of a ditch cross section number 1 derived from LiDAR data is shown in **Figure 14** with measurements in meters. The area below the orange line represents an area cross-section of excavation.

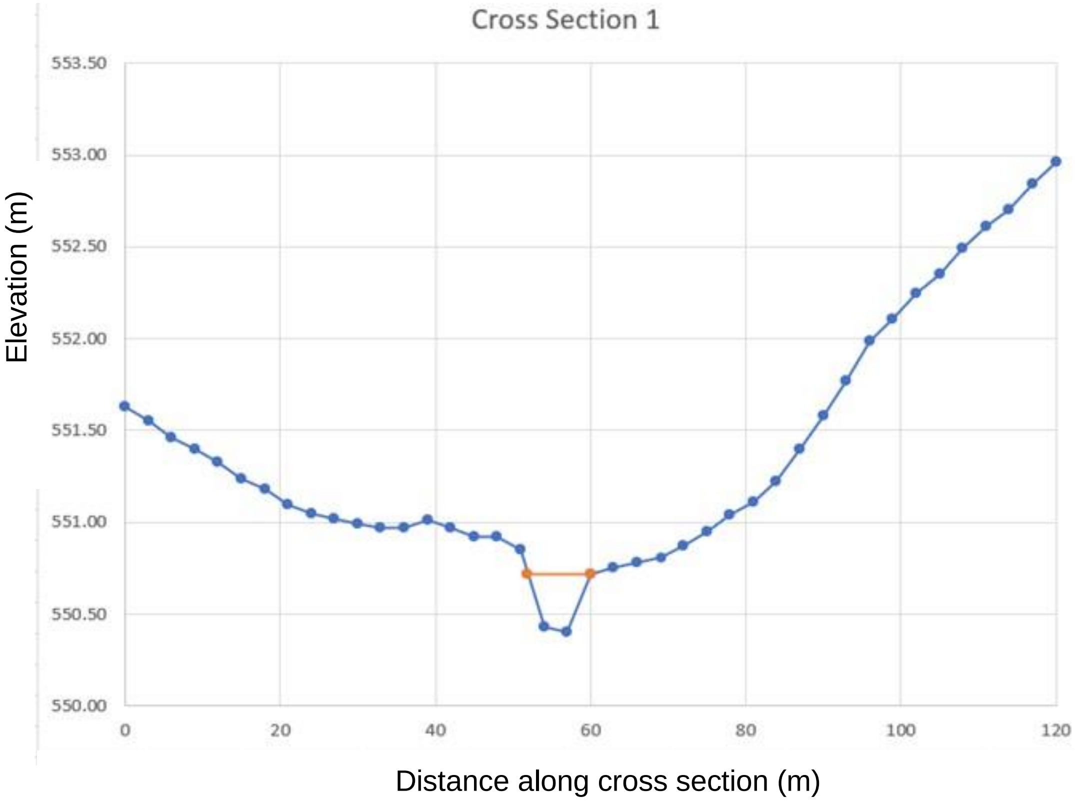

Figure 16. Cross section plot from LiDAR data.

Ditch volumes were totaled for each quarter section and plotted against total acres of wetlands drained. A relationship was established based on this data as shown in **Figure 15**.

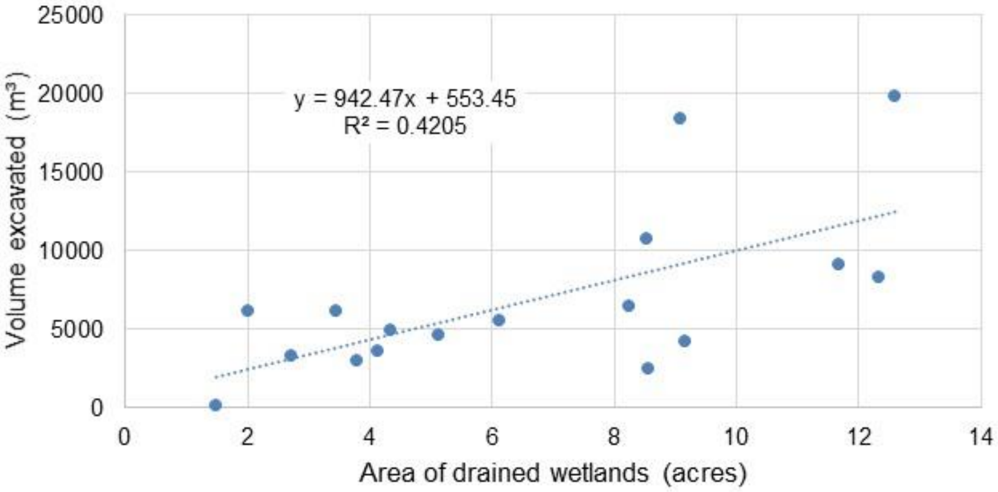

Figure 17. Drainage excavation volume versus area of wetlands drained (including partially drained) for 17 quarter sections at Arm River Farms.

The x coefficient of this relationship is used to predict that 942 m^3 of material would be excavated for every acre of wetland drained, or 2,328 m^3/ha. When this is factored together with an excavation cost of \$4/m^3, the result is an installation cost of \$9,310/ha of wetland drained. Based on a borrowing rate of 5% amortized over 25 years, the annual cost of draining 1 hectare of wetland is \$660.

The x coefficient of 942 m^3 per wetland acre drained and the excavation cost of \$4/m^3 is based on as subset data from the Dark Brown soil zone data set. Due to limitations of this report, the same data was used to predict drainage cost in the economic models for the Dark Brown soil and the Black soil zone data sets.

8.1.3 Overlap Costs

The Client provided an estimate of the overlap cost to be used for this economic model based on the analysis of 16 fields from the Dark Brown soil zone economic model. The fields had an average size of 189 ha (467 ac). Data files showing the field paths driven were downloaded from myjohndeere.com. ArcGIS was used to connect the points in sequence and calculate a total path length. This was then divided by the area under cultivation for the given field to determine the actual distance traveled per area under cultivation.

Implement widths were determined from field data by measuring the distance between parallel travel paths. This was 37 meters for the spraying operations and 20 meters for the seeding operations. The total area of spraying and seeding were calculated by multiplying the path length by the implement width. The percentage of overlap was calculated by dividing the area sprayed/seeded by the cultivated area in the field.

The linear relationship of percentage of overlap versus percentage of field that is intact (including partially drained) wetland was determined. This linear relationship was used in this study to model the overlap costs of retaining wetlands, assuming sectional control is not used. A fitted line plot was created from the overlap data, as shown in **Figure 16**, which reveals a coefficient of 1.486. Due to limitations of this report, this was used as the overlap index for the Dark Brown soil zone data set and the Black soil zone data set for both spraying and seeding.

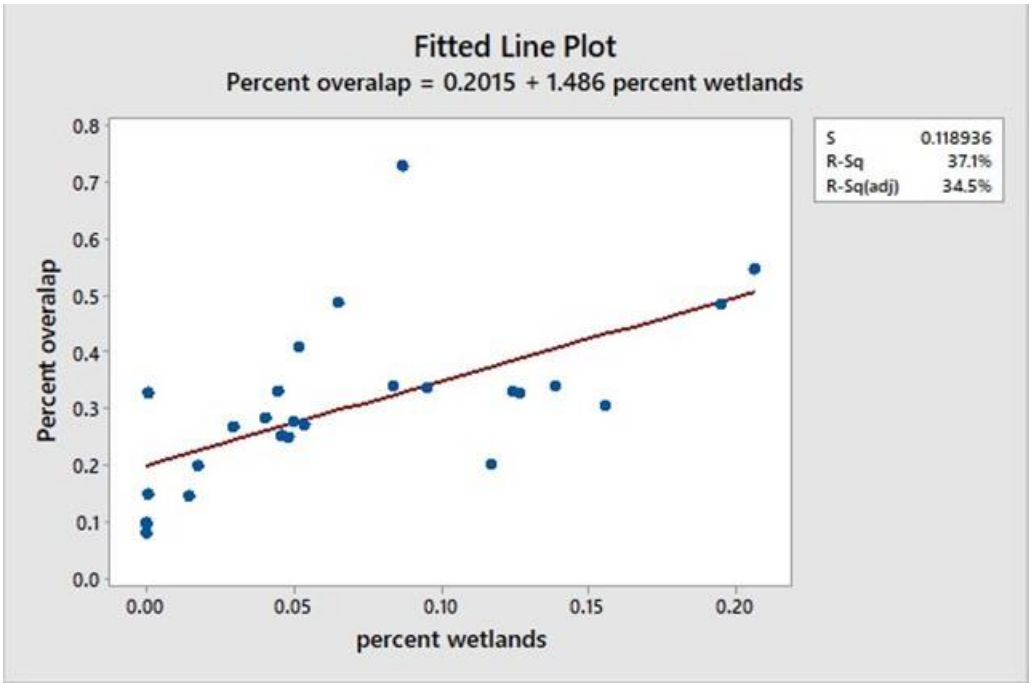

Figure 18. Percentage of overlap versus percentage of intact wetland field area.

To express this as a cost to the cultivated area, it was necessary to isolate the crop input expenses from the basic input costs of crop production. The crop input expenses for the Dark Brown and Black soil zone economic models are shown in **Table 29** and **Table 30**.

Table 29. Crop input expenses for the Dark Brown soil zone economic model.

	Spring Wheat	Canola	Yellow Peas
Seed	$30.60	$75.73	$71.20
Seed Treatments/Inoculants	$0.84	$9.00	$12.31
Fertilizer -Nitrogen	$141.15	$143.81	$11.85
-Phosphorous (P2O5)	$35.81	$49.45	$35.81
-Sulphur and Other	$0.00	$9.21	$0.00
Plant Protection -Herbicides	$63.33	$66.28	$72.41
-Insecticides	$21.89	$2.46	$15.22
-Fungicides	$19.35	$14.18	$14.18
Interest on Variable Expenses	$3.59	$4.25	$2.67
	$316.55	$374.36	$235.65

A unique overlap cost percentage was calculated for each scenario based on the percentage of field that was intact wetland area in the Dark Brown soil model:

- No-Drain Scenario: 4.98% of field is uncultivated wetland, Overlap = 7.40%
- Mitigation Scenario: 2.52% of field is uncultivated wetland, Overlap = 3.75%
- Fully Drained Scenario: 0% of field is uncultivated wetland, Overlap = 0%

The overlap cost percentage was factored together with the machinery operating expenses and cultivated area. The total overlap cost for each scenario in the Dark Brown Soil economic model was:

- No-Drain Scenario: $ 294,925
- Mitigation Scenario: $ 108,734
- Fully Drained Scenario: $0

Table 30. Crop input expenses for the Black soil zone economic model.

	Spring Wheat	Canola	Yellow Peas	Malt Barley
Seed	$30.60	$75.73	$71.20	$40.61
Seed Treatments/Inoculants	$0.84	$9.00	$12.31	$1.02
Fertilizer -Nitrogen	$141.15	$143.81	$11.85	$103.86
-Phosphorous (P2O5)	$35.81	$49.45	$35.81	$28.99
-Sulphur and Other	$0.00	$9.21	$0.00	$0.00
Plant Protection -Herbicides	$63.33	$66.28	$72.41	$63.78
-Insecticides	$21.89	$2.46	$15.22	$21.89
-Fungicides	$19.35	$14.18	$14.18	$19.35
Interest on Variable Expenses	$3.59	$4.25	$2.67	$3.21
	$316.55	$374.36	$235.65	$282.71

A unique overlap cost percentage was calculated for each scenario based on the percent of field that was intact wetland area in the Dark Brown soil economic model:

- No-Drain Scenario: 6.68% of field is uncultivated wetland, Overlap = 9.92%
- Mitigation Scenario: 3.97% of field is uncultivated wetland, Overlap = 5.89%
- Fully Drained Scenario: 0% of field is uncultivated wetland, Overlap = 0%

The overlap cost percentage was factored with the machinery operating expenses and cultivated area. The total overlap cost for each scenario in the Black soil zone Economic Model is as follows:

- No-Drain Scenario: $141,216
- Mitigation Scenario: $80,224
- Fully Drained Scenario: $0

8.1.4 Nuisance Costs

Due to limitations of this report, the ratio for overlap index was also used as the ratio for nuisance index for the Dark Brown and the Black soil economic models.

Relating this cost to unit area was necessary because as wetlands are drained on a field, the cultivated area changes.

To express this as a cost to the cultivated area, it was necessary to isolate the machinery operating expenses from the basic input costs of crop production for the Dark Brown and Black soil economic models (**Table 31** and **Table 32**).

Table 31. Machinery operating expense per acre for the Dark Brown soil zone economic model.

Machinery Expense ($/ha)	Spring Wheat	Canola	Yellow Peas
Machinery Operation: Fuel	$15.31	$16.21	$17.12
Repair	9.98	9.98	9.98
Custom Work and Hired Labour	22.05	21.05	20.30
Interest on Variable Expenses	0.54	0.54	0.54
Total Machinery Cost ($/ha)	$47.88	$47.78	$47.94

A unique nuisance cost percentage was then calculated for each scenario based on the percentage of field that was intact wetland area of the Dark Brown soil economic model:

- No-Drain Scenario: 4.98% of field is uncultivated wetland, nuisance = 7.40%
- Mitigation Scenario: 2.52% of field is uncultivated wetland, nuisance = 3.75%
- Fully Drained Scenario: 0% of field is uncultivated wetland, nuisance = 0%

The nuisance cost percentage was then factored with the machinery operating expenses and cultivated area. The total nuisance cost for each scenario in the Dark Brown soil economic model is listed as follows:

- No-Drain Scenario: $35,102
- Mitigation Scenario: $18,255
- Fully Drained Scenario: $0

Table 32. Machinery operating expense per acre for the Black soil zone economic model.

	Spring Wheat	Canola	Yellow Peas	Malt Barley
Machinery Operation: Fuel	$19.14	$20.27	$21.39	$19.14
Repair	11.29	11.29	11.29	11.29
Custom Work and Hired Labour	23.05	21.05	20.30	21.05
Interest on Variable Expenses	0.61	0.60	0.61	0.59
Total Machinery Cost ($/ac)	$54.10	$53.21	$53.59	$52.08

A unique nuisance cost percentage was then calculated for each scenario based on the percentage of field that was intact wetland area of the Black soil zone economic model:

- No-Drain Scenario: 9.45% of field is uncultivated wetland, nuisance = 9.43%
- Mitigation Scenario: 6.23% of field is uncultivated wetland, nuisance = 6.22%
- Fully Drained Scenario: 0% of field is uncultivated wetland, nuisance = 0%

The nuisance cost percentage was then factored with the machinery operating expenses and cultivated area. The total nuisance cost for each scenario in the Black soil zone economic model is listed as follows:

- No-Drain Scenario: $23,191
- Mitigation Scenario: $14,129
- Fully Drained Scenario: $0

8.1.5 Field Zone Areas and Buffer Overlap

The buffer zone raw data includes the overlap areas that occur when wetlands are less than 100 meters apart. This buffer with overlap data was multiplied by a correction factor to correct for overlap. The correction factor was developed from the client-supplied data for the total non-buffer area for the study. The buffer area was then calculated based on the following:

- Buffer Area = Total field area – Total Wetland area – non-buffer area.
- Buffer Correction Index = Buffer / Buffer with overlap.

In the Dark Brown soil zone data set, the total field area was 10,433 ac where 5,310 was non buffer area. The buffer area calculated based on the equation above was found to be 4,486 ac, and the buffer overlap area based on the sum of all buffer area polygons from the raw data was 5,060 ac. The ratio of these provided a buffer overlap correction index of 0.887, which was used to correct the buffer areas associated with each impact code for this study. A summary of the wetlands and updated buffer zone areas for calculations in the Dark Brown soil zone data set are summarized in **Table 33**

Table 33. Field zone areas for the Dark Brown soil zone data set.

Wetland Area		
	Impact Code	**Wetland Area (ac)**
Intact - no drainage	0	152
Partial	1	111
Farmed (not drained)	2	117
Completely drained	5	256
	total	637
Buffer Zone Area (corrected)		
	Impact Code	**Buffer Area (ac)**
Intact - no drainage	0	888
Partial	1	387
Farmed (not drained)	2	1844
Completely drained	5	1367
	total	4486

In the Black soil zone data set, the total field area was 4,689 ac where 1,387 was non-buffer area. The buffer area calculated based on the equation above was found to be 2,873 ac, and the buffer overlap area base on the sum of all buffer area polygons from the raw data was 5,317 ac. The ratio of these provided the buffer overlap correction index of 0.540, which was used to correct the buffer areas associated with each impact code for this study. A summary of the wetlands and updated buffer zone areas for calculations in the Black soil zone data set are summarized in **Table 34.**

Table 34. Field zone areas for the Black soil zone data set.

Wetland Area		
	Impact Code	**Wetland Area (ac)**
Intact - no drainage	0	117
Partial	1	69
Farmed (not drained)	2	133
Completely drained	5	127
	total	446
Buffer Zone Area (corrected)		
	Impact Code	**Buffer Area (ac)**
Intact - no drainage	0	558
Partial	1	215
Farmed (not drained)	2	1,369
Completely drained	5	731
	total	2,873

8.1.6 Field Zone Yield Response

The yield response index was based on the agronomic analysis for the wetlands and buffer areas by impact code for each crop type in the areas of study. The result was a matrix of values that described the yield responses for each crop in rotation. The values were applied in the economic model by multiplying the cultivated area for each field study zone by the yield index corresponding to the impact code matching the drainage scenario. This was multiplied by the crop production benefit to calculate the total crop benefit per acre.

The yield response matrices for the Dark Brown soil zone data set and Black soil zone data set are shown in **Table 35** and **Table 36**. In both cases, the matrix shown is the yield response for the **mitigation scenario**. The yield response for impact codes 0 and 1 wetlands are zero because by definition there is no crop grown there.

To simulate the **no-drain scenario**, the yield response of impact code 5 wetlands are set to impact code 0 and the corresponding yield response (of zero) applies. In a similar way, the yield response of impact code 5 buffer areas are set to impact code 0 and the corresponding yield response values apply. The values for impact code 2 wetlands and buffer areas remain unchanged.

To simulate the **fully drained scenario**, the yield responses of impact code 0 and 1 wetlands are set to impact code 5 and the corresponding yield response values apply. In a similar way, the yield response of impact code 0 and 1 buffer areas are set to impact code 5 yield response values. The values for impact code 2 wetlands and buffer areas remain unchanged.

Table 35. Dark brown soil economic model yield response matrix.

			Yield Response		
Field Study Zone	**Impact Code**		**Spring Wheat**	**Canola**	**Yellow Peas**
Wetland Intact - no drainage	0		0.000	0.000	0.000
Wetland Partial drainage	1		0.000	0.000	0.000
Wetland Farmed (not drained)	2		1.145	1.154	0.684
Wetland Completely drained	5		1.074	1.063	0.681
buffer (5-50)	0		0.829	0.821	0.796
buffer (5-50)	1		0.705	0.775	0.573
buffer (5-50)	2		0.985	1.040	0.953
buffer (5-50)	5		0.939	1.020	0.890
Non-Buffer (baseline yield)			1.000	1.000	1.000

The total crop benefit for each scenario in the Dark Brown soil Economic Model is presented as follows:

- No-Drain Scenario: $4,629,962
- Mitigation Scenario: $4,749,544
- Fully Drained Scenario: $4,872,508

Table 36. Black soil zone economic model yield response matrix.

		Yield Response Index			
Field Study Zone	**Impact Code**	**Spring Wheat**	**Canola**	**Yellow Peas**	**Malt Barley**
Wetland Intact - no drainage	0	0.0000	0.0000	0.0000	0.0000
Wetland Partial drainage	1	0.0000	0.0000	0.0000	0.0000
Wetland Farmed (not drained)	2	0.7920	0.7147	0.6520	0.7594
Wetland Completely drained	5	0.9193	0.8310	0.5047	0.7107
buffer (5-50)	0	0.7770	0.7790	0.5110	0.7960
buffer (5-50)	1	0.7540	0.8240	0.7060	0.7270
buffer (5-50)	2	0.9800	0.9800	0.9490	0.9550
buffer (5-50)	5	0.9670	0.9750	0.8570	0.9280
Non-Buffer (baseline yield)		1.0000	1.0000	1.0000	1.0000

The total crop benefit for each scenario in the Black soil zone economic model is presented as follows:

- No-Drain Scenario: $2,572,347
- Mitigation Scenario: $2,749,892
- Fully Drained Scenario: $2,949,951

8.1.7 Seeding Delay Effect on Yield

The effect of seeding delay was analysed as part of a sensitivity analysis in the economic model. The seeding delay effect on yield was based on data reported by MASC for crops grown in Manitoba for the period of 2010 to 2019. A graph of this data illustrates the effect of delay and is included in Figure 17

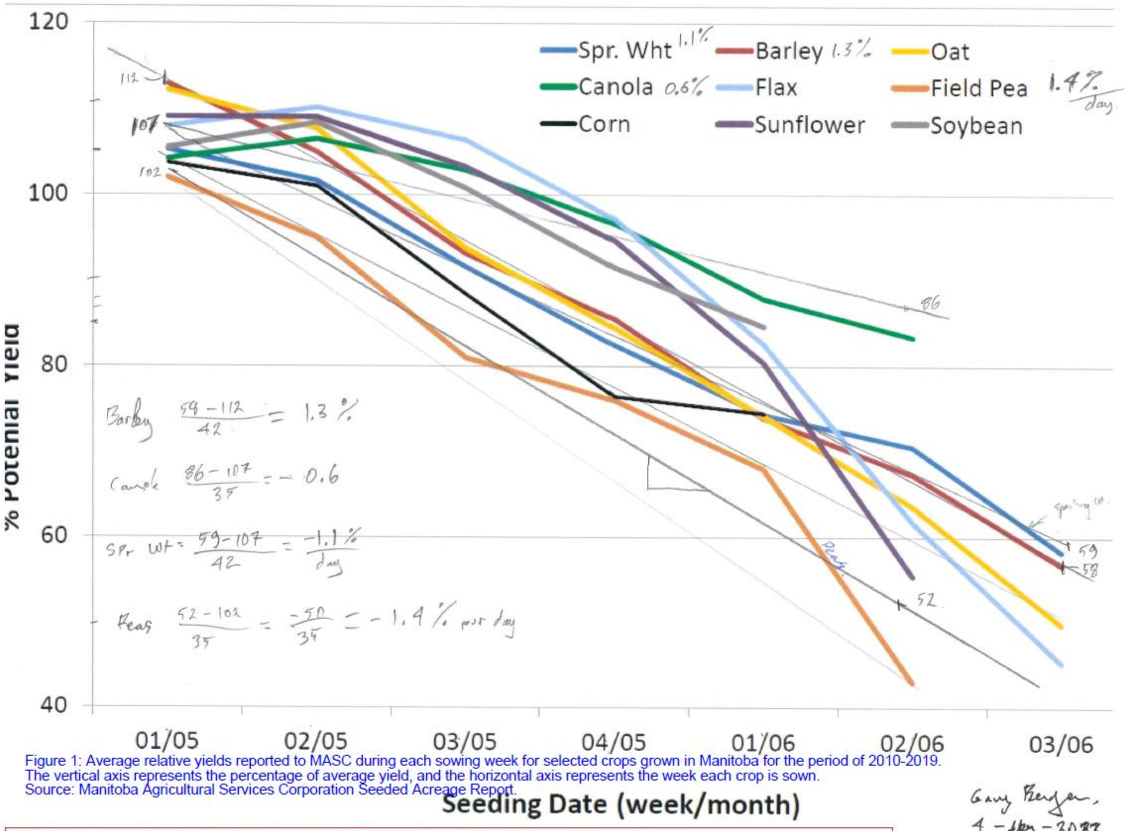

Figure 1: Average relative yields reported to MASC during each sowing week for selected crops grown in Manitoba for the period of 2010-2019. The vertical axis represents the percentage of average yield, and the horizontal axis represents the week each crop is sown.
Source: Manitoba Agricultural Services Corporation Seeded Acreage Report.

Gary Bergen,
4 - Apr - 2022

https://www.canolacouncil.org/canola-watch/2016/05/18/seeding-date-and-yield-graphs/

Figure 19. Effect of seeding delay on yield potential for various crops.

From this graph, unique values were calculated for each crop used in the economic model. The slopes of the straight-line approximations reveal the loss in yield per day of delay for each crop:

- Barley -1.3%/day,
- Canola -0.6%/day,
- Spring Wheat -1.1%/day,

- Peas -1.4%/day.

To simulate the effect in the economic model, these values were factored according to the yield matrix and the number of days of seeding delay.

The relationship of undrained wetlands on seeding delay is not within the scope of this report; however, it is generally understood that undrained land takes longer dry down to the point where it can support tractor and implement traffic, which can result in the seeding delay of an entire field. In this report the simple assumption was made that the fewer wetlands that are drained, the greater the delay for seeding a whole field and so a Fully Drained scenario would see 0 days of delay, a Partially Drained scenario would see 5 days of delay and the No Drainage scenario would see 10 days of delay. In this way, the sensitivity of seeding delay was explored to understand the potential cost of wetlands due to seeding delay of the whole field.

8.2 Results and Discussion

The economic models were created in Microsoft Excel. All results were displayed as an annual benefit per acre. There is a range of preference used to display the results from this study based on all acres or by all cultivated acres so results are presented in both ways. Using all acres as the basis for benefit shows the values of the entire land area to a producer. Using cultivated acres makes the benefits comparable to other fields independent of the number of uncultivated acres present from field to field. Furthermore, there is a range of preference for the basis of including or excluding sectional control. This means there are four base options for displaying the results; these are shown in **Table 37.**

Table 37. Four base options for displaying results.

Wetland Drainage Annual Benefit per Acre	
All Acres No Sectional Control	All Acres With Sectional Control
Cultivated Acres No Sectional Control	**Cultivated Acres With Sectional Control**

Cultivated Acres with sectional control was chosen as the preferred basis for displaying results. The reasoning is that farmland is generally valued based on the cultivated acres present, and sectional control has become readily available for most planting and spraying equipment. The results for this basis are listed for the Dark Brown soil economic model and the Black soil economic model in **Table 38** and **Table 39.** These tables each compare three drainage scenarios in terms of annual benefit in dollars per acre.

For results on the basis of all acres in the study and with or without sectional control see **Appendix D** for the Dark Brown soil economic model and **Appendix E** for the Black soil economic model.

Table 38. Annual benefit per acre for the Dark Brown soil economic model.

Wetland Drainage Annual Benefit per Acre			
Cultivated Acres: With Sectional Control			
Cultivated (%)	100%	97%	95%
Wetlands fully drained or farmed (%)	100%	59%	18%
Total Field Benefit per Acre	Fully Drained ($/acre)	Mitigation ($/acre)	No Drain ($/acre)
Drainage Annual	-$13.31	-$6.56	$0.00
Overlap c/w Sectional Control	$0.00	-$1.34	-$3.72
Nuisance	$0.00	-$1.80	-$3.54
Crop Production	-$467	-$467	-$467
Total Cost	-$480	-$477	-$474
Total Benefit	$653	$639	$629
Total Net	$173	$162	$155
Total Study Area (acres)	*10433*	*10433*	*10433*
Cultivated (acres)	*10433*	*10169*	*9913*

Table 39. Annual benefit per acre for the Black soil zone economic model.

Wetland Drainage Annual Benefit per Acre			
Cultivated Acres: With Sectional Control			
Area Cultivated (%)	100%	96%	93%
Wetlands fully drained or farmed (%)	100%	58%	30%
Total Field Benefit per Acre	Fully Drained ($/acre)	Mitigation ($/acre)	No Drain ($/acre)
Drainage Annual	-$17.85	-$7.55	$0.00
Overlap c/w Sectional Control	$0.00	-$2.23	-$4.03
Nuisance	$0.00	-$3.14	-$5.28
Crop Production	-$500	-$500	-$500
Total Cost	-$518	-$513	-$509
Total Benefit	$629	$611	$588
Total Net	$112	$98	$79
Total Study Area (acres)	*4689*	*4689*	*4689*
Cultivated (acres)	*4689*	*4503*	*4376*

8.2.1 General Results and Discussion

In general, the total net benefit per acre improves with the drainage of wetlands. This is the case regardless of the basis option used to display the results. For the dark brown soil economic model, the fully drained scenario predicts an $11 per acre (6%) increase in total net benefit per cultivated acre with the benefit of sectional control included where no drainage would reduce this by $7 per acre (4%). For the black soil economic model, the fully drained scenario predicts an $14 per acre (13%) increase in total net benefit per cultivated acre with the benefit of sectional control included where no drainage would reduce this by $19 per acre (19%).

The presence of sectional control has the effect of improving the net benefit per acre for the mitigation and no-drain scenarios. For the Dark Brown soil zone dataset, the total net benefit for the mitigation scenario improves from $153 per ac to $162 per ac and for the no-drain scenario from $129 per ac to $155 per ac. For the Black soil zone dataset, the total net benefit for the mitigation scenario improves from $83 per ac to $98 per ac and for the no-drain scenario from $51 per ac to $79 per ac.

The second line of the results table indicates the percentage of wetlands fully drained or farmed for each scenario. This indicates the percentage of total wetland area that is farmed including drained or undrained. In the study for the Dark Brown soil zone data set the no-drain scenario still has 18% of the total wetland area (2,080 ac) that is still farmed. In the study for the Black soil zone data set the no-drain scenario still has 30% of the total wetland area (133 ac) that is still farmed. For both studies, these are wetlands of impact code 2, farmed but not drained. In the mitigation and fully drained scenarios, these wetlands still remain at impact code 2. The significance here is that even the fully drained scenario included the benefit of retaining these 133 acres of wetland.

8.3 Sensitivity Analysis – Dark Brown Soil Zone Data Set

The following subheadings provide details regarding the sensitivity analysis for the Dark Brown soil zone data set.

8.3.1 Drainage Cost Sensitivity

The annual drainage cost for the fully drained scenario is $13.31 per cultivated acre, which is based on a ratio 942 m^3 of excavated volume per acre of wetland drained. It is understood that this coefficient could vary from one area to another based on topography characteristics, such as distance between wetlands and distance to field edge drain area. That is, regions of wetlands outside the study area may require a greater or lesser volume of excavation to drain.

A sensitivity analysis reveals that at a ratio of 2,400 m^3 excavated per acre of wetland drained (about 2.5 times higher), the model reveals the same net benefit of $152 per acre for both the mitigation and fully drained scenarios. The fully drained scenario has the highest total benefit; however, this is outweighed by the high annual drainage cost at $33.91 per ac. This sensitivity analysis indicates that the model is only moderately sensitive to changes in drainage cost. It would take a very expensive drainage cost in the order of $3,500 per wetland acre to make it not worth draining at all.

The use of sectional control technology becomes more significant to profitability than the effect of a fully drained scenario at a higher drainage cost. That is, the remaining wetlands could be retained with no loss to total net benefit with the use of sectional control.

8.3.2 Buffer Zone Yield

A unique aspect of this report is to study the change in yield in the buffer zones around wetlands that are drained vs undrained. The yield index of impact code 0 and 1 buffer zones is about 25% lower than impact code 5 buffer zone. So, to understand the effect of including this aspect in our study, a sensitivity analysis was done by factoring the yield index of impact code 0 and 1 buffer zones by 1.25, which basically eliminates the change in yield due to impact code.

This has no effect on the fully drained scenario, which remains at $173 per ac. However, the mitigation net benefit jumps from $162 per ac to $178 per ac and the no-drain net benefit jumps from $155 per ac to $191 per ac. Essentially, the economic benefit of draining wetlands is obscured if the effect of yield response by impact code in the buffer zone is ignored. This shows the importance of including the yield effect according to impact code in the buffer zone in this study.

8.3.3 Effect of Seeding Delay on Yield

The presence of wetlands on a field can result in the delay of seeding an entire field due to the additional spring drying days needed for the soil to support trafficability. A sensitivity analysis was done to add five seeding-delay days to the mitigation scenario and ten seeding-delay days to the no-drain scenario. The result of five days of seeding delay on the mitigation scenario resulted in a total net benefit drop from $178 per ac to $138 per ac. The result of ten days of seeding delay on the no-drain scenario resulted in a total net benefit drop from $191 per ac to $93 per ac.

While the actual delay in seeding due to wetlands is unknown, this sensitivity analysis reveals that the total net benefit of draining wetlands could be significantly amplified by reducing seeding delay. There could also be a significant challenge to net profitability if the retention of wetlands causes significant seeding delay.

8.4 Sensitivity Analysis for the Black Soil Zone Data Set

The following subheadings provide details regarding the sensitivity analysis for the Black soil zone data set.

8.4.1 Drainage Cost Sensitivity

The Drainage Annual cost for the Fully Drained scenario is $17.85 per cultivated acre, which is based on a ratio 942 m^3 of excavated volume per acre of wetland drained. It is understood that this coefficient could vary from one area to another based on topography characteristics, such as distance between wetlands and distance to field edge drain area. That is, regions of wetlands outside the study area may require a greater or lesser volume of excavation to drain.

A sensitivity analysis revealed that at a ratio of 2,200 m^3 excavated per acre of wetland drained (about 2.3 times higher), the model reveals the same net benefit of $88 per acre for the mitigation scenario and the fully drained scenario. The fully drained scenario has the highest total benefit; however, this is outweighed by the high annual drainage cost. This indicates that the model is only moderately sensitive to changes in drainage cost. It would take a very expensive drainage cost in the order of $2,200 per wetland acre to make it not worth draining at all.

The use of sectional control technology becomes more significant to profitability than the effect of a fully drained scenario at this higher drainage cost. That is, if higher drainage costs are experienced, the remaining wetlands could be retained with no loss to total net benefit with the use of sectional control.

8.4.2 Buffer Zone Yield

As with the Dark Brown soil zone (**Section 8.3.2**), yield index for was factored by 1.25 for impact codes 0 and 1 to remove the influence of yield difference for the sensitivity analysis.

This has no effect on the fully drained scenario, which remains at $112 per ac. However, the Mitigation net benefit jumps from $98 to $119 per ac and the No Drain net benefit jumps from $79 to $120 per ac. Essentially, the benefit of draining wetlands is obscured if the change in yield of the buffer zone is ignored. This shows the importance of understanding the change in yield effect according to impact code in the buffer zone.

8.4.3 Effect of Seeding Delay on Yield

As per the rationale for the Dark Brown soil zone sensitivity analysis (**Section 8.3.3**), the effect of seeding delay was evaluated.

A sensitivity analysis was done to add five days of seeding delay to the mitigation scenario and ten days of seeding delay to the no-drain scenario. the result of five days of seeding delay on the mitigation scenario resulted in a drop of total net benefit from $98 per ac to $66 per ac. The result of ten days of seeding delay on the no-drain scenario resulted in a drop in total net benefit from $79 per ac to $18 per ac.

While the actual delay in seeding due to wetlands is unknown, this sensitivity analysis reveals that the total net benefit of draining wetlands could be significantly amplified by reducing seeding delay. There could also be a significant challenge to net profitability if the retention of wetlands causes a significant seeding delay.

8.5 Landowner and Professional Review

On select occasions in the month of April 2022, the preliminary results of this report and the economic model were reviewed with landowners and agricultural professionals to provide feedback on the results. This was an important step in validating the study against landowner experience and also an indication of areas that could benefit from further study. The summary points from these reviews are organized by theme in **Appendix G**

9. Conclusions

The results from this study indicate that there are many variables that impact the effectiveness of agricultural drainage (both economically, and agronomically).

Agronomically, the results from both datasets signify that there are some key variables that are common in significance, including impact code, wetland class, year, crop type, and field, as well as some key interactions between these variables. For comparisons of the single interactions, the yield in the wetlands alone displayed some similar trends, including a large variance in yields by year as well as a large variance in yields by crop type and field. Between the two datasets, the yield in the buffer zone (5-50-meter zone) displayed the same significant variables with similar trends. Impact code, for example, showed that in both datasets, farmed and completely drained wetlands had significantly higher yields compared to intact and partially drained wetlands. Both datasets displayed the same trend when comparing wetland classes with temporary wetlands yielding significantly higher than permanent wetlands by up to 30%. A limitation is that this is an observational study rather than one involving experimental manipulation and means that the results should be validated with further field experiments.

The two-way interaction comparisons also displayed very similar interactions across the two datasets in the buffer area. In the Black soil zone, completely drained wetlands, on average, yielded significantly better than other impact codes in temporary, seasonal, and semi-permanent wetlands whereas the permanent wetlands showed varying response levels. In the Dark Brown soil zone, the results displayed that both farmed, and completely drained wetlands yielded similarly, but greater than intact and partially drained wetlands across the varying wetland classes.

The results of crop response in the 5-50 buffer zone by impact code were a key variable contributing to the economic analysis performed within this study. For barley, both datasets displayed the greatest yield response in farmed and completely drained wetlands when compared to intact and partially drained wetlands, with partially drained yielding the lowest (significantly). For canola, both datasets, again, displayed a significantly higher yield for the farmed and completely drained wetlands versus the intact and partially drained. The data for the peas showed that farmed wetlands yielded the highest (significantly), followed by completely drained wetlands (both significantly higher than intact and partially drained). Finally, the wheat yields also showed that farmed and completely drained wetlands yielded significantly higher than intact and partially drained wetlands in both datasets. These results indicate that overall, each crop type in most scenarios benefits from either being completely drained or farmable.

The models consistently showed an economic net benefit to draining wetlands. A sensitivity analysis of increased drainage costs reveals an increased advantage of sectional control technology. A sensitivity analysis of yield response in the buffer zone reveals that the economic benefit of drainage is obscured unless the yield effect in both the wetland and the buffer zone is included.

Yield response of drainage greatly varies by many different factors, such as year, crop type, impact code, and wetland class. The main message from this study is that drainage response can be highly variable: in some instances, there were significant responses by drainage but in others, there were not huge responses. Understanding the significant variables for specific datasets will more greatly aid in determining whether agricultural drainage is both economically and agronomically practical in specific situations.

There is an opportunity for future work in this area to understand the full agronomic and economic effects of wetland drainage. Topics recommended for further study include the age effect of wetland drainage (i.e., five years ago vs. ten years ago), as the contrasting effects of salinity and soil property are expected to trend toward the field average and stabilize over time. An economic analysis could provide greater accuracy to the economic model. Such areas of study to be included are

- further study on the effectiveness of sectional control systems,
- drainage cost data, including other drainage systems options, and
- expanding nuisance costs to include other equipment such as grain carts, nuisance associated with slower speeds with more obstacles, and nuisance between various equipment sizes.

Further study to define the crops in rotation would also serve to reveal a broader understanding of wetland drainage, such as crop inputs specific to the study data, including input variability and an expansion on the crop production guide assumptions (i.e., labour costs).

10. Glossary of Terms

ANOVA – a statistical analysis of variance (used to determine statistical significance)

Borrowing Rate – the interest rate used to determine the annual cash flows to offset the initial investment

Buffer Overlap – area where 50 m buffer zones from one wetland overlap with the buffer zones of another

Buffer Zone/ Buffer Distance – defined in 5-meter increments to a maximum of 50 meters from the wetland border- the “zone” is the area within the increments

DEM – Digital Elevation Model: representation of the topography of the terrain of the test area

Drainage – the process of redirecting water one area to another predefined area

Impact code – the state of the wetland in terms of drainage; defined as Intact (0), Partially Drained (2), Farmed (3), Constructed (4), Partially Filled (5), Completely Drained (6) or consolidated (7)

LiDAR – Light Detection and Ranging- remote sensing method using light to determine topography and surface characteristics (measures ranges/distances to the earth)

Mechanical Overlap – equipment coverage overlap based on actual upland field area, area of wetlands and path travelled utilizing available data (seeding, spraying, harvesting)

Nuisance Cost – cost associated with machinery time, speed changes etc. with working around wetlands

Sectional Control – or sectional control technology refers to and implement where flow of crop input (seed, fertilizer, herbicide) is controlled independently to an associated sections of an implement and furthermore there is control in place to shutdown the flow of crop input as the implement reaches areas that have been previously treated.

Tukey Analysis – or “Tukey’s Honest Significant Difference (HSD) Test”, is a post hoc test to compare the means of treatments and determine differences among those means (pairwise comparison test)

Wetland Class – designated as Ephemeral (Class 1), Temporary (Class 2), Seasonal Ponds and Lakes (Class 3), Semi-permanent Ponds and Lakes (Class 4), Permanent Ponds and Lakes (Class 5), Alkali Ponds and Lakes (Class 6) and Fen Ponds (Class 7)

WSA – Water Security Agency

11. References

Agriculture and Agri-Food Canada. (2009, March). *Salinity Class.* Retrieved from Soils of Saskatchewan : https://soilsofsask.ca/documents/sksid_usermanual.pdf

Alberta Agriculture and Rural Development. (2001, November 1). *Goverment of Alberta- All Resources.* Retrieved from Salt tolerance of plants: https://open.alberta.ca/dataset/2818626

Bevans, R. (2020, March 6). *ANOVA in R: A step-by-step guide.* Retrieved from Scribbr: https://www.scribbr.com/statistics/anova-in-r/

Government of Canada. (2021, September 9). *Station Results- Historical Data*. Retrieved from Weather, Climate and Hazard: https://climate.weather.gc.ca/historical_data/search_historic_data_e.html

Government of Canada. (2022, 03 02). *Historical Data*. Retrieved from Government of Canada: Past weather and climate: https://climate.weather.gc.ca/historical_data/search_historic_data_e.html

Government of Saskatchewan. (2022). *Crop Planning Guide and Crop Planner*. Retrieved from Government of Saskatchewan: https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/farm-business-management/crop-planning-guide-and-crop-planner

Government of Saskatchewan. (2022). *Dry Pea Fact Sheet.* Retrieved from Government of Saskatchewan : https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/field-crops/pulse-crop-bean-chickpea-faba-bean-lentils/dry-pea

Hector, A., von Felten, S., & Schmid, B. (2010). Analysis of vartiance with unbalance data: an update for ecology and evolutions. *Journal of Animal Ecology, 79*, 308-316.

Langsrud, O. (2003). ANOVA for unbalance data: Use type II instead of type III sums of squares. *Statistics and Computing, 13*, 163-167.

Manitoba Agriculture. (2008). *Soil Management Guide.* Retrieved from Food and Rural Initiatives: https://www.gov.mb.ca/agriculture/environment/soil-management/soil-management-guide/pubs/soil-management-guide.pdf

Manitoba Agriculture. (2022). *Agriculture Forages for Imrpoving Saline Soils.* Retrieved from Forage Production and Management: https://www.gov.mb.ca/agriculture/crops/crop-management/forages/forage-production-and-management.html

Appendix A

Historical Weather Data

Tukey Analysis Results - Black and Dark Brown Soil Zone Dataset

Elkhorn 2 East MB

Year	2014	2015	2016	2017	2018	2019	2020	Grand Total
January	20.8	16.2	9.2	22.6	8.0	14.6	21.4	**112.8**
February	11.2	11.8	19.0	18.4	3.6	15.4	2.4	**81.8**
March	16.0	25.2	43.4	29.6	37.4	2.2	31.4	**185.2**
April	64.8	8.6	34.2	12.0	7.4	18.4	12.8	**158.2**
May	61.4	18.4	80.2	17.0	51.9	23.4	22.6	**274.9**
June	225.0	59.0	92.6	85.8	125.3	42.6	87.4	**717.7**
July	23.2	126.2	104.6	24.0	46.8	45.2	56.8	**426.8**
August	114.2	49.4	19.4	38.2	20.4	82.8	24.2	**348.6**
September	49.6	44.4	68.6	59.6	72.4	109.4	17.4	**421.4**
October	3.4	15.8	102.0	5.6	36.0	21.0	9.0	**192.8**
November	35.4	10.2	9.4	31.6	38.0	19.4	11.0	**155.0**
December	4.0	18.0	40.6	17.6	9.4	5.8	19.2	**114.6**
Grand Total	**629.0**	**403.2**	**623.2**	**362.0**	**456.6**	**400.2**	**315.6**	**3189.8**

Virden MB (2014 data not available due to instrumentation error)

Year	2014	2015	2016	2017	2018	2019	2020	Grand Total
January	-	21.0	6.0	4.0	7.0	44.0	16.0	**98**
February	-	27.0	17.0	8.0	6.0	8.6	0.8	**67.4**
March	-	22.0	5.0	N/A	N/A	0.0	8.2	**35.2**
April	-	9.5	24.6	9.2	N/A	15.9	14.8	**74**
May	-	55.8	55.8	15.4	62.8	23.7	19.0	**232.5**
June	-	82.9	2.6	34.0	100.7	80.6	60.0	**360.8**
July	-	173.4	29.6	3.2	56.9	35.1	118.0	**416.2**
August	-	76.6	6.4	41.4	24.7	117.8	6.0	**272.9**
September	-	52.4	63.8	97.6	73.0	117.0	13.6	**417.4**
October	-	31.1	110.0	4.0	12.1	15.2	5.0	**177.4**
November	-	12.5	17.0	20.0	17.0	1.0	2.0	**69.5**
December	-	24.0	0.0	9.0	5.0	0.0	N/A	**38**
Grand Total	**-**	**588.2**	**337.8**	**245.8**	**365.2**	**458.9**	**263.4**	**2259.3**

Kipling SK

Year	2014	2015	2016	2017	2018	2019	2020	Grand Total
January	20.0	26.0	9.0	19.0	8.0	9.6	13.4	**105.0**
February	12.0	18.0	13.0	14.0	9.0	28.4	2.0	**96.4**
March	23.5	18.4	26.9	14.0	46.6	0.0	16.6	**146.0**
April	64.8	15.7	38.0	8.1	13.4	26.2	14.6	**181**
May	61.8	20.8	86.6	25.2	49.1	14.4	23.0	**281**

June	190.8	38.6	101.4	98.2	148.6	115.0	44.2	**737**
July	21.2	72.0	85.8	12.6	49.4	34.4	42.6	**318**
August	116.3	51.8	39.2	21.4	27.0	88.0	68.4	**412**
September	56.2	73.2	54.6	22.2	35.4	112.6	20.6	**375**
October	10.0	48.0	97.6	7.4	38.6	29.2	5.2	**236**
November	23.8	16.8	14.6	16.6	20.0	13.4	7.8	**113.0**
December	4.0	20.2	24.0	14.0	6.8	5.6	21.6	**96.2**
Grand Total	**604**	**419.5**	**590.7**	**272.7**	**451.9**	**476.8**	**280.0**	**3096.0**

Dark Brown soil zone analysis monthly precipitation data by weather station, year, and month

Last Mountain

Year	2016	2017	2018	2019	Grand Total
January	8	6.1	4.1	6	24.2
February	7.8	8.5	2.9	8.4	27.6
March	14.8	5.1	25.8	1.6	47.3
April	9.6	14.1	4.4	8.9	37
May	50.6	10.8	34.4	11.4	107.2
June	39.5	27.2	76.6	68.2	211.5
July	127.5	5.1	22.5	6.6	161.7
August	33	51.5	17.7	58.4	160.6
September	38.1	22.8	35.4	64.3	160.6
October	40.6	62.7	11.8	11.4	126.5
November	5.6	11.9	9.2	9	35.7
December	7.1	3.5	1.8	1.5	13.9
Grand Total	**382.2**	**229.3**	**246.6**	**255.7**	**1113.8**

Moose Jaw

Year	2016	2017	2018	2019	Grand Total
January	5	19.6	1.1	7.4	**33.1**
February	8.2	26	7.1	15.9	**57.2**
March	12.1	11.8	18.5	0.2	**42.6**
April	11.2	13.6	9.2	17.3	**51.3**
May	100.5	12.7	32.8	3.5	**149.5**
June	58.6	34.4	47	111.5	**251.5**
July	81.8	4.3	20.1	29.9	**136.1**
August	64.1	43.9	18.1	86.9	**213**
September	49	7.3	31.5	104.8	**192.6**
October	100.3	26	17.7	9.8	**153.8**
November	9.4	13.7	16	14.6	**53.7**
December	15.2	4.9	9.9	2.7	**32.7**
Grand Total	**515.4**	**218.2**	**229**	**404.5**	**1367.1**

Regina

Year	2016	2017	2018	2019	Grand Total
January	5.9	3.8	3.3	4.8	17.8
February	6.3	8.4	4.3	12.3	31.3
March	19.4	4.4	21	0.8	45.6
April	10.2	20.2	5.1	20.2	55.7
May	73.5	6.9	25.4	11.3	117.1
June	58.3	46	43.9	76.7	224.9
July	74.3	1.8	19.5	50.3	145.9
August	58.3	11.1	17.4	95.7	182.5
September	54	11.1	27.6	78.5	171.2
October	64.5	22.2	22.6	10.6	119.9
November	6.7	11.2	8.2	11.3	37.4
December	5.7	4.3	5.2	2.3	17.5
Grand Total	437.1	151.4	203.5	374.8	1166.8

Appendix B

WSA Data Attributes

Polygon Descriptors	Individual Polygon Data Points	Location Attributes	Crop Yield Statistics
polygon ID	impact code	year	harvest area (m^2)
field code	wetland class	crop type	min yield
field	polygon area (m^2)	precipitation (mm) – agronomic interpretation only	max yield
wetland number	buffer overlap area (m^2)		yield range
buffer zone	wetland area (m^2)		yield mean
			yield std
			yield sum
			field mean
			crop yield as a percentage of field mean

Appendix C

Tukey Analysis Results – Black and Dark Brown Soil Zone Dataset

Black Soil Zone Dataset Tukey Analysis Results

- **In wetland:**

  - Single interactions:

Yield (as a percentage of field average) and Tukey groupings of wetland data (0-meter buffer zone only) by year.

Year	2014	2015	2016	2017	2018	2019	2020
Yield/ Tukey Grouping	64.6 ab	52.5 a	58.6 ab	64.5 b	63.8 b	96.2 c	96.3 c

Yield (as a percentage field average) and Tukey groupings by crop type.

Crop	Barley	Canola	Wheat	Yellow Peas
Yield/ Tukey Grouping	74.7 a	75.7 a	83.8 b	58.6 c

Yield (as a percentage of field average) by field.

Field	Yield
Bauche	64.5
Bisset	82.3
Chucks	51.5
Dunham	71.7
FFA_ra	66.9
HLC_Ho	70.3
Hogart	92.0
Lipsey	79.2
Mccon	64.5
Mel_1	65.0
NW_14	83.4
R_Oliv	55.8
Roy_Ya	98.7
Roys	101
Swallo	64.2
Vics	99.0

  - Two-way Interactions:

Yield (as a percentage of field average) of impact code by year.

Year	2014	2015	2016	2017	2018	2019	2020
Impact Code 2- Farmed	64.2	51.4	58.7	63.0	55.9	93.3	95.1
Impact Code 5- Completely Drained	65.3	54.8	58.3	68.2	77.5	101	98.7

- **In buffer:**

  - Single Interactions:

    Yield (as a percentage of field average) and Tukey groupings by year.

Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Yield/ Tukey Grouping	86.4 ab	86.8 a	85.0 b	91.3 cd	92.6 c	94.0 d	96.7 e

Yield (as a percentage field average) and Tukey groupings by crop type.

Crop	**Barley**	**Canola**	**Wheat**	**Yellow Peas**
Yield/ Tukey Grouping	92.3 a	92.5 b	92.4 b	83.4 c

Yield (as a percentage of field average) and Tukey groupings of buffer zones 5-50.

Buffer Zone	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
Yield	83.0	87.4	89.9	91.4	92.5	93.8	94.6	95.3	95.8	96.1
Tukey Grouping	a	b	c	cd	de	ef	f	fg	fg	g

Yield (as a percentage of field average) by field.

Field	**Yield**
Bauche	96.1
Bisset	96.4
Chucks	78.5
Dunham	91.7
FFA_ra	96.1
HLC_Ho	88.4
Hogart	98.5
Lipsey	91.6
Mccon	75.9
Mel_1	86.4
NW_14	99.6
R_Oliv	81.1
Roy_Ya	95.0
Roys	94.3
Swallo	94.0
Vics	98.6

  - Two-way Interactions:

    Yield (as a percentage of field average) by buffer zone, by year, including 0-meter wetland average.

Buffer Distance	**5m**	**10m**	**15m**	**20m**	**25m**	**30m**	**35m**	**40m**	**45m**	**50m**
2014	75.3	78.1	83.4	83.7	85.2	88.3	90.5	91.1	90.4	91.2
2015	62.4	72.3	80.2	84.8	88.2	91.7	93.5	94.2	94.9	95.3
2016	68.2	76.5	82.3	85.2	85.7	86.6	87.5	89.3	90.5	91.0
2017	76.7	82.8	86.8	90.2	91.8	94.2	95.7	96.9	96.7	96.9
2018	77.8	86.0	90.1	92.7	94.3	95.7	96.3	96.7	96.7	96.9
2019	94.1	94.4	93.3	92.6	92.6	93.3	93.9	94.5	95.4	95.9

2020	94.2	95.4	95.9	96.0	96.7	97.2	97.1	97.6	98.0	98.4

Yield (as a percentage of field average) of impact code, by year.

Impact Code	0	1	2	5
2014	81.2	73.3	91.2	81.3
2015	70.1	62.4	93.8	85.2
2016	55.2	58.2	91.4	93.6
2017	75.9	81.1	98.2	91.8
2018	78.5	81.7	96.9	99.0
2019	79.5	81.0	99.6	98.8
2020	83.8	88.0	101	101

Yield (as a percentage of field average) of buffer zone, by crop type.

Buffer Distance	5	10	15	20	25	30	35	40	45	50
Barley	81.6	87.1	90.8	92.1	92.5	93.7	94.2	95.1	96.0	96.2
Canola	82.4	87.3	90.3	92.0	93.3	94.6	95.2	95.7	96.0	96.3
Wheat	85.8	88.7	90.0	91.0	92.0	93.3	94.5	95.3	96.0	96.3
Yellow Peas	70.7	75.8	79.2	81.6	83.5	85.9	86.8	88.4	88.9	89.6

Yield (as a percentage of field average) of wetland class by crop type.

Wetland Class	2	3	4	5
Barley	96.2	87.4	81.9	78.2
Canola	98.0	86.4	80.9	69.8
Wheat	98.4	86.3	80.8	65.1
Yellow Peas	90.9	76.3	65.3	53.6

Yield (as a percentage of field average) of buffer zone, by wetland class.

Buffer Distance	5	10	15	20	25	30	35	40	45	50
2	89.1	94.1	96.8	98.3	98.8	99.5	99.7	99.9	99.7	99.7
3	74.1	78.9	83.0	84.6	86.1	88.0	89.1	90.4	91.2	91.7
4	70.8	73.5	74.2	75.8	78.3	81.3	84.3	86.6	88.1	89.4
5	56.1	56.8	56.2	59.8	65.1	70.5	73.2	76.1	80.7	83.8

Yield (as a percentage of field average) of wetland class by year.

Wetland Class	2	3	4	5
2014	89.9	81.1	70.6	72.6
2015	93.4	77.8	76.2	64.1
2016	91.5	76.8	72.7	58.1
2017	96.6	89.2	77.2	69.2
2018	98.5	86.8	78.4	65.9
2019	99.5	87.8	82.2	68.4
2020	101	91.1	88.1	78.1

Yield (as a percentage of field average) of buffer zone, by field.

Buffer Distance	5	10	15	20	25	30	35	40	45	50
Bauche	78.9	86.0	91.7	95.2	97.3	100	102	103	102	101
Bisset	90.0	94.1	96.1	97.9	97.8	98.6	96.9	96.4	97.1	97.4
Chucks	62.8	69.4	73.7	75.6	77.4	80.0	81.0	83.8	87.5	89.9
Dunham	79.2	85.0	89.5	91.7	92.9	94.6	94.4	95.0	94.8	95.9
FFA_ra	84.3	92.5	94.0	95.2	96.4	97.6	98.1	99.0	101	102

HLC_Ho	79.5	83.3	87.6	87.0	88.5	90.2	90.9	90.5	91.2	91.9
Hogart	91.3	96.5	99.1	99.7	99.1	98.8	99.6	100	100	100
Lipsey	84.4	89.0	90.8	90.5	90.8	91.6	93.0	94.6	94.4	96.1
Mccon	66.8	68.9	71.3	74.3	76.1	78.6	77.6	77.0	79.7	80.0
Mel_1	74.1	79.7	82.7	85.0	86.4	88.0	89.7	90.9	92.1	93.7
NW_14	88.1	93.4	95.7	97.9	101	103	104	104	104	104
R_Oliv	68.1	74.9	78.1	79.4	81.0	82.3	83.9	85.9	86.9	87.2
Roy_Ya	94.6	94.6	94.1	94.1	94.9	95.5	95.5	95.7	95.3	95.4
Roys	94.3	95.2	93.3	93.2	92.7	93.1	93.4	94.8	95.9	96.3
Swallo	73.3	81.3	88.4	93.7	96.7	99.0	100.5	101	101	99.9
Vics	99.3	98.9	98.6	97.5	97.3	97.6	98.4	98.9	99.5	99.7

Dark Brown Soil Zone Dataset Tukey Analysis Results

- **In wetland:**
  - Single Interactions:

Yield (as a percentage of field average) and Tukey groupings by year.

Year	2016	2017	2018	2019
Yield/ Tukey Grouping	62.2 a	98.8 b	128 c	123 c

Yield (as a percentage of field average) and Tukey groupings of crop type.

Crop	Barley	Canola	Wheat	Yellow Peas
Yield/ Tukey Grouping	101.6 ab	112.1 b	68.2 ab	112.3 a

Yield (as a percentage of field average) by field.

Field	Yield
ABBN	142.8
ABJN	118.1
ABLO	117.9
ABMA	102.2
ABRI	122.6
ABTS	119.7
ABWE	87.5
ABWW	100.2
AJPI	127.7
ALJU	89.9
AMIE	115.0
AMIS	116.2
AOHO	99.3
APEE	83.8
APNS	111.0
GBIL	119.4
GCOO	107.5
GGER	85.5
GGOR	106.3
GPAL	109.3

- **In buffer:**
  - Single Interactions:

Yield (as a percentage of field average) and Tukey groupings by year.

Year	2016	2017	2018	2019
Yield/ Tukey Grouping	87.8 a	92.0 b	98.7 c	94.9 c

Yield (as a percentage of field average) and Tukey groupings of buffer zones 5-50.

Buffer Zone	5	10	15	20	25	30	35	40	45	50
Yield	102	98.4	93.7	90.6	89.3	89.7	90.8	92.4	93.8	95.0
Tukey Grouping	a	b	cfgh	def	e	e	ef	fg	gh	h

Yield (as a percentage of field average) and Tukey groupings of crop type.

Crop	Barley	Canola	Wheat	Yellow Peas
Yield/ Tukey Grouping	94.4 a	97.7 b	92.5 c	87.4 d

Yield (as a percentage of field average) by field.

Field	Yield
ABBN	99.9
ABJN	96.2
ABLO	96.7
ABMA	85.0
ABRI	95.7
ABTS	98.2
ABWE	91.9
ABWW	96.9
AJPI	101
ALJU	89.6
AMIE	93.4
AMIS	85.5
AOHO	90.4
APEE	93.0
APNS	88.4
GBIL	96.9
GCOO	94.1
GGER	94.5
GGOR	101
GPAL	102

- Two-way Interactions:

Yield (as a percentage of field average) by buffer zone, by year, including 0-meter wetland average.

Buffer Distance	5m	10m	15m	20m	25m	30m	35m	40m	45m	50m
2016										
2017										
2018										
2019										

Yield (as a percentage of field average) of impact code, by year.

Impact Code	0	1	2	5
2016				
2017				
2018				
2019				

Yield (as a percentage of field average) of buffer zone, by crop type.

Buffer Distance	5	10	15	20	25	30	35	40	45	50
Barley										
Canola										
Wheat										
Yellow Peas										

Yield (as a percentage of field average) of wetland class by crop type.

Wetland Class	2	3	4	5
Barley				
Canola				
Wheat				
Yellow Peas				

Yield (as a percentage of field average) of impact code, by buffer zone.

Buffer Distance	5	10	15	20	25	30	35	40	45	50
0										
1										
2										
5										

Yield (as a percentage of field average) of wetland class by year.

Wetland Class	2	3	4	5
2016	91.5	76.8	72.7	58.1
2017	96.6	89.2	77.2	69.2
2018	98.5	86.8	78.4	65.9
2019	99.5	87.8	82.2	68.4

Yield (as a percentage of field average) of buffer zone, by field.

Appendix D

Dark Brown Soil Zone Data Set: Additional Results on Basis of All Acres, With or Without Sectional Control.

All Acres, No Sectional Control: Annual Benefit per Acre for the Dark Brown Soil Zone Data Set

All Acres: No Sectional Control			
Cultivated (%)	100%	97%	95%
Wetlands fully drained or farmed (%)	100%	59%	18%
Total Field Benefit per Acre	Fully Drained ($/acre)	Mitigation ($/acre)	No Drain ($/acre)
Drainage Annual	-$13.31	-$6.56	$0.00
Cost of Overlap (no sectional control)	$0.00	-$10.42	-$28.27
Nuisance	$0.00	-$1.75	-$3.36
Crop Production	-$467	-$455	-$444
Total Cost	-$480	-$475	-$479
Total Benefit	$653	$623	$598
Total Net	$173	$147	$119
Total Study Area (acres)	*10433*	*10433*	*10433*
Cultivated (acres)	*10433*	*10169*	*9913*

All Acres, With Sectional Control: Annual Benefit per Acre for the Dark Brown Soil Zone Data Set

All Acres: With Sectional Control			
Cultivated (%)	100%	97%	95%
Wetlands fully drained or farmed (%)	100%	59%	18%
Total Field Benefit per Acre	Fully Drained ($/acre)	Mitigation ($/acre)	No Drain ($/acre)
Drainage Annual	-$13.31	-$6.56	$0.00
Overlap c/w Sectional Control	$0.00	-$1.30	-$3.53
Nuisance	$0.00	-$1.75	-$3.36
Crop Production	-$467	-$455	-$444
Total Cost	-$480	-$465	-$451
Total Benefit	$653	$623	$598
Total Net	$173	$158	$147
Total Study Area (acres)	*10433*	*10433*	*10433*
Cultivated (acres)	*10433*	*10169*	*9913*

Cultivated Acres, No Sectional Control: Annual Benefit per Acre for the Dark Brown Soil Zone Data Set

Cultivated Acres: No Sectional Control			
Cultivated (%)	100%	97%	95%
Wetlands fully drained or farmed (%)	100%	59%	18%
Total Field Benefit per Acre	Fully Drained ($/acre)	Mitigation ($/acre)	No Drain ($/acre)
Drainage Annual	-$13.31	-$6.73	$0.00
Cost of Overlap (no sectional control)	$0.00	-$10.69	-$29.75
Nuisance	$0.00	-$1.80	-$3.54
Crop Production	-$467	-$467	-$467
Total Cost	-$480	-$486	-$500
Total Benefit	$653	$639	$629
Total Net	$173	$153	$129
Total Study Area (acres)	*10433*	*10433*	*10433*
Cultivated (acres)	*10433*	*10169*	*9913*

Appendix E

Black Soil Zone Data Set: Additional Results on basis of all acres, with or without sectional control

Table 40. All Acres, No Sectional Control: Annual Benefit per Acre for the Black Soil Zone Data Set

All Acres: No Sectional Control			
Cultivated (%)	100%	96%	93%
Wetlands fully drained or farmed (%)	100%	58%	30%
Total Field Benefit per Acre	Fully Drained ($/acre)	Mitigation ($/acre)	No Drain ($/acre)
Drainage Annual	-$17.85	-$7.25	$0.00
Cost of Overlap (no sectional control)	$0.00	-$17.11	-$30.12
Nuisance	$0.00	-$3.01	-$4.93
Crop Production	-$500	-$480	-$466
Total Cost	-$518	-$509	-$505
Total Benefit	$629	$586	$549
Total Net	$112	$77	$44
Total Study Area (acres)	*4689*	*4689*	*4689*
Cultivated (acres)	*4689*	*4503*	*4376*

Table 41. All Acres, With Sectional Control: Annual Benefit per Acre for the Black Soil Zone Data Set

All Acres: With Sectional Control			
Cultivated (%)	100%	96%	93%
Wetlands fully drained or farmed (%)	100%	58%	30%
Total Field Benefit per Acre	Fully Drained ($/acre)	Mitigation ($/acre)	No Drain ($/acre)

Drainage Annual	-$17.85	-$7.25	$0.00
Overlap c/w Sectional Control	$0.00	-$2.14	-$3.76
Nuisance	$0.00	-$3.01	-$4.93
Crop Production	-$500	-$480	-$466
Total Cost	-$518	-$492	-$475
Total Benefit	$629	$586	$549
Total Net	$112	$94	$74
Total Study Area (acres)	*4689*	*4689*	*4689*
Cultivated (acres)	*4689*	*4503*	*4376*

Table 42. Cultivated Acres, No Sectional Control: Annual Benefit per Acre, for the Black Soil Zone Data Set

Cultivated Acres: No Sectional Control			
Cultivated (%)	100%	96%	93%
Wetlands fully drained or farmed (%)	100%	58%	30%
Total Field Benefit per Acre	Fully Drained ($/acre)	Mitigation ($/acre)	No Drain ($/acre)
Drainage Annual	-$17.85	-$7.55	$0.00
Cost of Overlap (no sectional control)	$0.00	-$17.82	-$32.27
Nuisance	$0.00	-$3.14	-$5.28
Crop Production	-$500	-$500	-$500
Total Cost	-$518	-$528	-$537
Total Benefit	$629	$611	$588
Total Net	$112	$83	$51
Total Study Area (acres)	*4689*	*4689*	*4689*
Cultivated (acres)	*4689*	*4503*	*4376*

Appendix F

Agronomic Assumption from the Dark Brown Soil Zone (Government of Saskatchewan, 2022)

	Seed	Fertilizer	Plant Protection	Machinery Operating	Custom Work and Hired Labour	Crop Insurance Premium	Utilities and Miscellaneous	Interest on Variable Expenses	Other
Spring Wheat	22 plants/sq ft target plant stand	Nitrogen: 95 lb/ac P2O5: 37 lb/ac	Based on provincial insect, disease and weed pressure	Based on diesel priced $0.901/litre with a repair rate of 2.6% of yearly machinery investment	Labour assumed to be $26.40 per hour for custom farm operations	Five-year averages of premiums by producers who attained targeted yield	Cost of electricity, natural gas water and telephone expenses	A rate of 3.01% used on all variable expenses applied for 8 months	Buildings, property and machinery
Canola	5 lb/ac seeding rate	Nitrogen: 100 lb/ac P2O5: 54 lb/ac Sulphur: 15 lb/ac							
Yellow Peas	158 lb/ac seeding rate	Nitrogen: 8 lb/ac P2O5: 37 lb/ac							

Agronomic Assumption from the Black Soil Zone (Government of Saskatchewan, 2022)

	Seed	Fertilizer	Plant Protection	Machinery Operating	Custom Work and Hired Labour	Crop Insurance Premium	Utilities and Miscellaneous	Interest on Variable Expenses	Other
Spring Wheat	25 plants/sq ft target plant stand	Nitrogen: 78 lb/ac P2O5: 34 lb/ac	Based on provincial insect, disease and weed pressure	Based on diesel priced $0.901/litre with a repair rate of 2.6% of yearly machinery investment	Labour assumed to be $26.40 per hour for custom farm operations	Five-year averages of premiums by producers who attained targeted yield	Cost of electricity, natural gas water and telephone expenses	A rate of 3.01% used on all variable expenses applied for 8 months	Buildings, property and machinery
Canola	5 lb/ac seeding rate	Nitrogen: 108 lb/ac P2O5: 58 lb/ac Sulphur: 15 lb/ac							
Yellow Peas	178 lb/ac seeding rate	Nitrogen: 9 lb/ac P2O5: 42 lb/ac							
Barley	25 plants/sq ft target plant stand	Nitrogen: 78 lb/ac P2O5: 34 lb/ac							

Appendix G

Agronomic Results and Economic Model Review with Landowners (WSA and PAMI, April 2022)

Review of PAMI agronomic and economic work

As part of WSA's Mitigation Research and Demonstration Projects, Prairie Agricultural Machinery Institute (PAMI) was asked to examine the agronomic and economic effects of several demonstration projects. This included looked at yield data from drained and undrained wetlands and building an economic model to examine the net profit from various drainage scenarios. During April 2022, the preliminary results from these analyses for the Black Soil Zone were presented to five landowners four professionals (MoA **economist**, MOA agronomist, wetland scientist and a private agronomist) to provide feedback on the results. This process is an important step in validating the results of the study against landowner experience. Below are the summary points from these meetings organized by theme:

Overlap

- Overlap effect seems high. Landonwer would expect based on his experience 30% overlap with 20% to 30% wetlands as a percent of field.
- Overlap costs seems high.
- Overlap effect seems high but might be real.
- Sectional control has probably been adopted on 90% of spraying acre sand 60% of seeding acres.

Whole Field effect

- A wet field could have a seeding delay of 5-25 days depending on the weather.
- Whole field effect might be more of a whole farm effect (e.g., farms in the Allan Hills).
- Whole field effect will be tricky to parcel out since some fields are always seeded before others.
- Temporary wetlands that are farmed but not drained may be a main driver of the 'whole field effect".

Magnitude of economic benefit

Field average approach is understandable, but the level of drainage might bias the field average and so the relative responses.

- Model summary should reflect total acres farmed.
- $50 is a good minimum spread between fully drained and no drainage. More likely is $100 based on landowner's experience and as shown by some of the sensitivity analysis.
- Expression of percent change in margin is really important. Would this be sensitive changes in price cross structure? Would the absolute spread change if prices change?

- Might be useful to express this as a change in percent net from a base value of land making $25/acre net.
- Assumptions should have moderate values for the sake of credibility.
- $50 spread between drianed and not drained scenarios is a good middle road average for communicating
- Since the buffer yield response is the main driver in the economic model, this number is really important to get right.
- Agronomic results seem to make sense.
- Economic results match very closely the costs and net return that one landowner sees in their own books.
- The wet conditions in the 2010-2020 decade led to unusually high and persistent pond levels, as compared to the previous 5 decades. Groundwater observation well records show similar high groundwater levels during the 2010-2020 decade. It seems that the productivity changes in the buffer zones should be interpreted in the light of these unusually wet conditions.

Costs of drainage

- $500-700/acre drainage costs seem far too low for one landowner's area. This might work Class Is, II's. $3800 wouldn't be out of line for some more permanent wetlands.
- Costs at $3800/acre are way too high $500-700 reflect more the reality on one landonwer's farm.
- Costs of drainage are probably about $1000-2000/acre

Other components or comments

- Assumptions around 30% farmed and using current crop production guide are OK approaches.
- People should be made aware of the huge amount of work and data that went into this.
- In the Black Soil zone Crop production Guide scenario, the phosphate cost seems high
- The economic analysis is complex, and this will be tricky to communicate effectively to producers. Many high-end producers will look at the average numbers and think that they do better than the average. People will tend to get stuck on details of the numbers.
- Crop production guide might overestimate the inputs that get put in.
- A shorter rotation with canola might be something worth considering. If you grow canola every second year, this might change things.
- Might be good to do a couple of rotation scenarios. Wheat/Canola Rotation scenario?
- Canola might typically be more like 30% to 50% of rotation.

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