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Does drainage pay? Quantifying agricultural profitability associated with wetland drainage practices and canola production in Alberta

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Abstract Conversion of wetlands in cultivated agricultural landscapes is one of the primary drivers of wetland loss in Alberta, Canada, despite a provincial wetland policy that prioritizes wetland avoidance. While other sectors of the agricultural industry have established initiatives to maintain wetlands, a common narrative within the conventional cropping sector is that wetland retention leads to lost acreage and overlap of crop inputs, and that there are financial benefits associated with wetland drainage. The objective of this research was to explicitly quantify crop productivity within drained wetland basins, in an effort to better understand the extent to which producers financially benefit from drainage practices. Working collaboratively with canola producers in central Alberta over the 2019 growing season, wetland basins within four quarter sections were mapped using an Unmanned Aerial Vehicle, and wetland basins with clear evidence of surface drainage were identified. Agricultural input and yield data provided by producers was then used to quantify profitability within each drained basin. Average profit for drained basins for each producer ranged between − $145/acre and $76/acre, with an average of $55/acre across all operations. This is compared to an average profit of $203/acre for non-wetland areas across all operations. The results suggest that the financial benefits of drainage are highly variable, and for many drained basins, producers may experience financial losses that may be overlooked when profits are examined only at the field- or operation-level. While this study included a small number of operations, and was limited to one type of crop over a single growing season, the results still provide important insight into the extent to which producers benefit financially from the practice of wetland drainage.

Keywords Wetlands · Drainage · Profitability · Agriculture

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Introduction

The Canadian Prairies are one of the major food producing regions on the planet, and within the Province of Alberta, extensive fields of wheat, canola, and pasturelands have led to thriving rural communities that have been an integral component of the

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provincial economy and identity since European settlement (AARD 2007; Government of Alberta 2020a). As with many other regions of North America, the history of agrarian settlement in Alberta has resulted in profound changes to the landscape (Gage et al. 2016); as of 2015, approximately 20% of lands within the province have been converted to agricultural land use, making agriculture the most dominate human footprint type in Alberta (ABMI 2017). This land conversion has been driven by several factors, including local and global demands for food, grassland and parkland ecosystems that provide excellent soils and relatively simple cultivation, and a history of productivist agricultural policies and permissive water laws that have encouraged water diversion and wetland drainage (Percy 1993; Clare 2013; Mills et al. 2017; Watmough et al. 2017).

While historic wetland loss in Alberta has not been precisely measured, the central and southern portions of the province are part of the Prairie Pothole Region (PPR) where it is estimated that 90% of wetland area has been lost due to agriculture (Van Meter and Basu 2015). This habitat loss has resulted in steep declines in biodiversity, the removal of natural carbon storage and flood control systems, as well as increased nutrient levels in water sources for downstream communities (Euliss et al. 2006; Armstrong 2018; Ameli and Creed 2019; Reid et al. 2019; Albert et al. 2020). The negative impacts of wetland loss on the supply of essential ecosystem services has led to a general increase in awareness regarding the importance of wetland conservation, and in some cases, has prompted private and public action to prevent further loss of these benefits (Weber et al. 2017). In Alberta, for example, the provincial government released a new wetland policy in 2013 that prioritizes avoidance of wetland habitat, and requires compensation for lost habitat primary through the restoration of degraded wetlands such as those that have been drained for agricultural production (Government of Alberta 2013, 2018).

Despite the rising awareness around the benefits that wetlands provide and resultant government policies to prevent their loss, wetland ecosystems in Alberta continue to be drained for agricultural use (Clare and Creed 2014; Watmough et al. 2017). While the livestock sector in Canada has implemented a number of sustainability programs related to wetland conservation, such as the Environmental Stewardship Award and the Canadian Roundtable for Sustainable Beef (CRSB 2018), the crop sector has been slower to adopt similar practices (CRSC 2020). This difference may be due in part to the strong focus in the cropping sector on increasing agricultural productivity, which is the ratio of the total output of crop and livestock products to the total inputs of land, labour, capital, and materials used to produce a given output. Given the strong linkage between productivity and profitability, large investments have been made into science, technology, and best management practices to increase the productivity of a given parcel of land (Yost et al. 2019). Further, when viewed through the lens of increasing agricultural productivity, wetland retention as a management practice is thought by many producers to reduce productivity (Tarnoczi and Berkes 2009; Greenland-Smith et al. 2016).

A common narrative amongst agricultural producers is that retaining wetlands causes fragmentation of fields, thereby reducing operational efficiency, while at the same time decreasing the overall gross acreage available for crop production (Chenard and Parkins 2010; Brandes et al. 2016). Thus, many producers in Alberta use drainage ditches to remove unwanted surface water from fields, or to consolidate surface water from many small wetlands into a single large wetland. A strong motivation for producers to drain wetlands is a belief that the area within the drained basin will be available for cultivation, and further, that crop productivity within the drained basin will be sufficient to offset input costs. Producers also employ wetland drainage in an effort to increase operational efficiency within a field, such that they are able to drive through, rather than around, a wetland. In many cases, however, drainage may not be as effective as desired; for example, large or deep basins are often incompletely drained, making them too wet to seed or drive through in the spring, thereby eliminating these areas from cultivation and requiring producers to drive around them. Alternatively, producers may choose to cultivate within an incompletely drained basin, but the excess soil moisture may reduce yields to a point where the input costs exceed the output value, resulting in a financial loss. This outcome may be particularly common in years where spring or summer precipitation is higher than average. In these cases, the increase in agricultural production likely results in only modest financial gains, while there may be instances where cultivation within a drained basin results in a financial loss to the producer, in addition to the loss or impairment of wetland ecosystem services.

Quantifying the benefits and costs of different wetland management practices within agricultural landscapes has been studied through different disciplinary lenses. For example, an economic farm productivity model by Cortus et al. (2011) suggests that converting natural areas to croplands produces a financial benefit. When viewed through the lens of ecosystem services, other research asserts that the financial benefit of wetland retention does not outweigh the financial benefit of converting a wetland to agriculture when a single ecosystem service, such as flooding, is considered; however, when multiple ecosystem services are considered, both the financial and environmental argument for wetland retention is strong (Pattison et al. 2011; Pattison-Williams et al. 2018). Sub-field analyses that allows for targeted management at the field level support this assertion. For example, Brandes et al. (2016) concludes that incorporating conservation management that breaks even (such as planting low-input perennials) makes financial sense, and further suggest that incorporating these actions on low-yielding cultivated areas could increase overall cropland profitability by 80% if such integration occurred. Other research suggests that strategic integration of perennials is a useful tool for crop producers to meet conservation goals and access government support programs or new markets (Brandes et al. 2018; Galpern and Gavin 2020).

Given that many crop producers drain wetlands with the aim of increasing productivity and profits, it is important to critically examine whether this common practice actually produces a financial benefit, and if so, to understand the magnitude of that benefit. Further, because many jurisdictions and conservation organizations are contemplating using policy tools such as payments for ecosystem services to incentivize wetland retention, understanding the extent of the financial benefits associated with drainage can help inform the design of these programs. Consequently, the objective of this study was to assess how the practice of wetland drainage influences the productivity and profitability of canola production at the sub-field level. This study focused specifically on canola because it is one of the most profitable cash crops in prairie Canada, and its production value often drives the conversion of natural habitats (Rashford et al. 2011). The standard practice for canola production is to adopt a three-year crop rotation, where canola is rotated annually with other crops to minimize impacts associated with disease and pests. Because of this rotation practice, our study only includes a single year of data. Nevertheless, this study serves to illustrate how quantifying crop production at the sub-field level can contribute to a more complete understanding of how wetland drainage influences overall profits, which may otherwise be overlooked when assessing profitability at the field- or operation-scale.

Study area

This study was conducted in Camrose County, a rural municipality located in central Alberta, Canada (Fig. 1). Camrose County is located within the Parkland Natural Region and the Prairie Pothole Region of North America, which is characterized by an abundance of small marsh wetlands. Agriculture is the primary industry in Camrose County, and intensive livestock operations, large scale grain and oilseed production, and small family farming operations are common throughout the County (Camrose County 2020).

Methodology

Site selection

Producer participation was critical to the success of this study, and in March of 2019, nine agricultural producers were identified as potential partners. These producers were members of the personal or professional networks of our research team and collectively held over 70 quarter sections of land in Camrose County. The focus of the initial contact was to describe the objective of the research, discuss the willingness of producers to grant our team access to their lands and their seeding and harvest data, and to determine which producers would be planting canola in the spring of 2019.

For those producers who were willing to participate and had fields that would be planted to canola, our team gathered and reviewed current and historical air photographs for each operation. One image per decade, spanning between 1960 and 2010, was

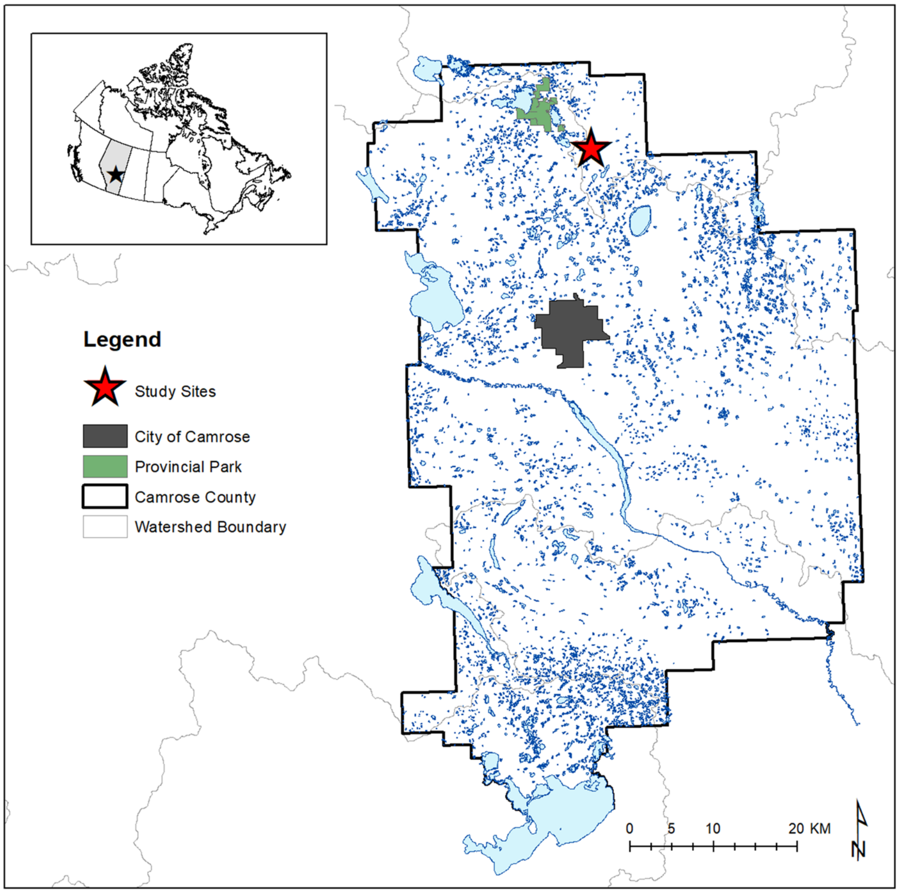

Fig. 1 Location of study sites within Camrose County in central Alberta, Canada

obtained from the provincial air photo library, with more recent historical imagery accessed through Google Earth and ESRI basemaps. A climate analysis was completed for the region to provide context for each image. The objective of this image review was to identify operations that had more than one wetland with a visible drainage ditch within a contiguous field. A contiguous field was considered to be a single quarter section (160 acres or 65 ha) or multiple quarter sections planted to a single crop. Ultimately, three producers with four quarter sections were recruited: Producers 1 and 2 both had a single quarter section, while Producer 3 had two contiguous quarter sections of land that were suitable for inclusion in the study.

Aerial surveys and wetland mapping

An Unmanned Aerial Vehicle (UAV) was used to collect aerial imagery of each study site in mid-June, directly after seeding and just prior to plant emergence. The imagery was collected using a Canon ELPH 110 camera (16 Mpixel) that was onboard a senseFly eBee fixed-wing UAV. Pix4D MapperPro software (version 3.3.13, Pix4D SA, Lausanne, Switzerland) was used to produce a 3D point-cloud using structure from motion methods and a 2D orthomosaic with a ground sample distance (resolution) of 4 cm/pixel. Ground control point (GCP) targets that were visible in the imagery and surveyed in the field provided horizontal and vertical geometric control for all UAV image products.

The 3D point-cloud was processed in ENVI (5.3, Exelis Visual Information Solutions, Boulder, Colorado) to create a bare ground Digital Terrain Model (DTM) for each study site. Whitebox GAT (Lindsay 2016) and ArcGIS (10.6, ESRI) were used to process the DTM into a variety of terrain products that were used to identify the location of wetland basins and delineate the approximate boundary of each wetland. The location of the wetland basins and boundaries were reviewed and adjusted in a Geographic Information System using a combination of the UAV imagery and historic air photographs.

Each wetland was assigned a management status (drained, consolidated, or hydrologically intact) based on a review of the available imagery. A wetland was defined as drained if the basin had a clearly visible drainage ditch in one or more image, and a consolidated wetland appeared to receive surface water from one or more drained wetlands. Hydrologically intact wetlands had no obvious drainage channels or other visible evidence of changes to surface water flow pathways due to ditching. An estimated wetland permanence class was assigned to each hydrologically intact wetland using the Alberta Wetland Classification System (Table 1; AESRD 2015). Because of the extensive hydrological modifications that are typically associated with drainage, a water permanence class was not assigned to wetlands identified as drained or consolidated.

Profitability modelling

A financial profitability model was created based upon a return on investment (ROI) framework for agricultural productivity (see Brandes et al. 2016). For the 2019 growing season, each producer provided our team with input and operational cost values for seeding, fertilizer and chemical applications, fuel, labor, insurance (crop and hail), and machinery depreciation. These costs were combined to calculate an average cost/acre value for each operation. Additionally, producers provided spatially explicit canola yield data collected by precision farming equipment. Revenues were calculated based upon yield estimates from harvesters, 2019 canola prices, and carbon payments. Based upon established literature (Brandes et al. 2016; McWilliams 2018), the following profitability equation was developed:

$$\begin{aligned} P_{ijw} = {} & \left[\left(Y_{ij} x P_{ij}\right) + \left(P_c\right)\right] - \left[\left(\left(P_{seed} * q\right) + \left(P_{herb} * q\right)\right.\right. \\ & + \left(P_{pest} * q\right) + \left(P_N * q\right) + \left(P_P * q\right) \\ & \left.\left. + \left(P_{machine} + P_{labour}\right) + \left(P_{insurance}\right)\right)_{ij} + R_{jl}\right)\Big], \end{aligned} \tag{1}$$

where P_{ijw} is the profitability of crop i in year j for the wetland area w, Y_{ij} is the yield, P_{ij} is the crop price in 2019, and P_c is the carbon payment received per acre. The production costs included seed, herbicide, pesticide, nitrogen, phosphorous, machine, labour and insurance costs. R can be included for rental lands.

Canola yield data collected by precision agriculture equipment was provided by each producer, and the data were converted into a raster layer that was resampled to a resolution of 0.5 × 0.5 m to create a consistent mapping scale across all fields. The yield data was assumed to be accurate to within ± 3% (Luck

Table 1 Wetland permanence classes and descriptions, as per the Alberta Wetland Classification System (AESRD 2015)

Wetland permanence class	Class description
Ephemeral	Terrain affected by the water table near, at or above the ground surface for a short period of days, but not long enough to promote the formation of water altered soils within 30 cm of the ground surface or a dominance of water tolerant vegetation
Temporary	Basin typically flooded every year for a short period of time after snowmelt or a heavy rainfall, but otherwise lacks surface water; affected by the water table for long enough to promote formation of water altered soils within 30 cm of ground surface and a dominance of water tolerant vegetation during parts of the growing season
Seasonal	Basin typically flooded for most of the growing season but has little to no surface water remaining by the end of summer
Semi–permanent	Bains typically flooded year–round, except in years when drought conditions persist
Permanent	Water levels are near, at or above the ground surface for variable periods during the year. Water is less than 2 m deep at midsummer and basin contains an open water zone that covers more than 25% of the total area in the majority of years

and Fulton 2014). The yield data was then used to create a revenue map for each field, and the average input and operational cost value calculated for each operation was subtracted from the revenue map to create a spatially explicit profit/loss map. For each field, an average profit/acre value was calculated. Additionally, the wetland map for each field was overlaid on the profit/loss map and the total profit and average profit/acre for each individual basin was calculated according to wetland management status (hydrologically intact or drained/consolidated). For comparison, the average profit/acre for each field was also calculated for areas outside of wetland basins. A simple aggregate ROI calculation was completed for sensitivity analysis using annual costs and projected changes in inputs prices, yield, and canola prices. All costs are in CAD$2019.

Climate analysis

Daily observed precipitation data for the Camrose Weather Station was downloaded from the Alberta Government current and historical weather station data viewer (Government of Alberta 2020b) for the period January 1, 2018 to December 31, 2020. Total monthly precipitation values (mm) were summarized using the hydroTSM package in R (Zambrano-Bigiarini 2020).

Producer interviews

Semi-structured interviews with producers were conducted in December 2019. These interviews included discussions about the 2019 field operations (seeding dates, moisture conditions, yields compared to previous years), wetland management (attitudes, awareness of existing policy and legislation), broad environmental sentiments and attitudes, and motivations for farming. A second interview was conducted in July 2020, where the profit and loss data from their operation were presented to each producer. Discussions in this interview were focused on understanding each producer's impression of the results, and whether the results provided motivation to change current approaches to wetland management. Each producer interview was attended by a husband and wife team, and took approximately 2 h in a location chosen by the producer. Prior to engaging with the producers, the interviewer communicated that there was no wetland advocacy bias being presupposed by the research, and that the results of the study would be used to help inform the current understanding of wetland management practices and potential opportunities for improving environmental policy outcomes in Alberta. The results of the interviews were used by our team to provide context for the results of the productivity analysis, as well as to gauge the willingness of these producers to change their production and/or wetland management practices in light of new information about wetland management and agricultural productivity.

Results

Field-level profitability modelling

Average input costs for each producer ranged between \$274 and \$323/acre, with average field-level profits ranging between \$147.28 and \$257.70/acre (Table 2). Overall profitability for each operation was assessed through a return on investment (ROI) analysis that calculated the cost and revenue ratio using producer input costs and average canola yield and prices. ROI ratios for all operations were > 1 (range = 1.50 to 1.77), indicating that despite a challenging growing season that included a wet summer and fall (Fig. 2), all three producers averaged more than \$100/acre. During interviews, producers indicated that \$100/acre is a benchmark for canola production in the region, with profits above this benchmark being considered by producers to be a good financial return, and profits less than this benchmark being considered somewhat disappointing.

Sub-field profitability modelling and mapping

A total of 140 marsh wetlands were identified and mapped across each of the three agricultural operations (Fig. 3). 64 Wetlands (46%) were classified as being drained or consolidated; the remaining 76 wetlands appeared to be hydrologically intact, with more than two thirds of the intact wetlands being classified as ephemeral wetlands.

When wetland boundaries were overlaid onto the profitability maps, some clear patterns emerged (Fig. 4). For several of the wetlands, there was limited (or no) profitability data associated with the basin.

Table 2 Field-level costs and profits associated with each agricultural operation

	Average input cost ($/acre)	Average field–level profit ($/acre)
Producer 1	323.50	257.70
Producer 2	274.67	234.70
Producer 3	297.78	147.28

This is because the producer did not seed or cultivate these areas; therefore, there was no input or output data associated with these locations. In other cases, there was a clear correlation between the location of wetlands and areas of low profit or financial loss, meaning that input costs exceed revenue in these locations. Finally, there were several instances where wetland boundaries correspond to areas of moderate to high profit, where revenue exceeded input costs.

Total profit for a single drained or consolidated basin was highly variable, ranging from a loss of $179.59 to a profit of $1838.43, with the average profit/acre ranging between − $288.0 and $442.22 (Tables 3, 4, 5, 6; Fig. 5). Hydrologically intact basins had higher average profit/acre values than drained or consolidated wetlands; however, for Producer 2, the average profit for these basins was still below the $100/acre benchmark value (Table 3). By comparison, the average profit/acre for cultivated lands outside wetland basins ranged between $155.57 and $264.43, with an average profit of just under $204/acre across all operations. A summary of each individual wetland basin, including information about Management status, wetland size, the area and proportion of the basin that was cultivated, the total profit, and the average profit/acre is provided separately for Producer 1 (Table 4), Producer 2 (Table 5), and Producer 3 (Table 6).

Discussion

For most agricultural producers, annual profits or losses are calculated on an aggregate level; either at a field-scale or at the scale of the entire operation (Cortus et al. 2009). Producers that utilize precision agriculture equipment also have access to more detailed information about their field-scale operations (Capalbo et al. 2017; Yost et al., 2019). For example, producers can spatially track within-field input costs if they use variable seeding or fertilizer application rates, while also tracking harvest volumes within each field. While this data is available to producers who utilize precision agriculture technology in newer equipment, it is not typically combined together to derive an overall spatial map of profitability. As such, this study presents a unique and spatially explicit view of sub-field profit that provides a more nuanced view of how wetland management practices impact profits than can be understood from the more common approach of calculating aggregate-level profits or loss.

The finding that there is spatial variability in agricultural productivity within each field is not surprising or novel, and producers have intuitive and experiential knowledge about the areas in their fields that consistently produce variable or low yields (Chenard and Parkins 2010). Often these areas are associated with undesirable soil or moisture conditions, including low wet areas that flood annually or seasonally. Given this knowledge, the producers who participated in this study were not surprised to learn that there were financial losses associated with wetlands in their fields; they did, however, express surprise at the magnitude of the loss in some of the areas. In this single year of production and across all fields, 56% of the drained and consolidated basins yielded a financial loss, with Producer 2 experiencing a financial loss in 90% of their drained and consolidated basins. When compared against the $100/acre benchmark, 70% of the drained and consolidated basins produced less than the desired profit. Overall, total and average profits associated with the hydrologically intact basins were better than for the drained and consolidated basins, and this can likely be attributed to the high proportion of ephemeral wetlands that make up the intact basins. Despite the comparably higher profits associated with the intact basins, 30% of the basins yielded a financial loss, with 55% of the basins producing below the desired $100/acre benchmark.

When asked whether the profitability information from this study would change their approach to

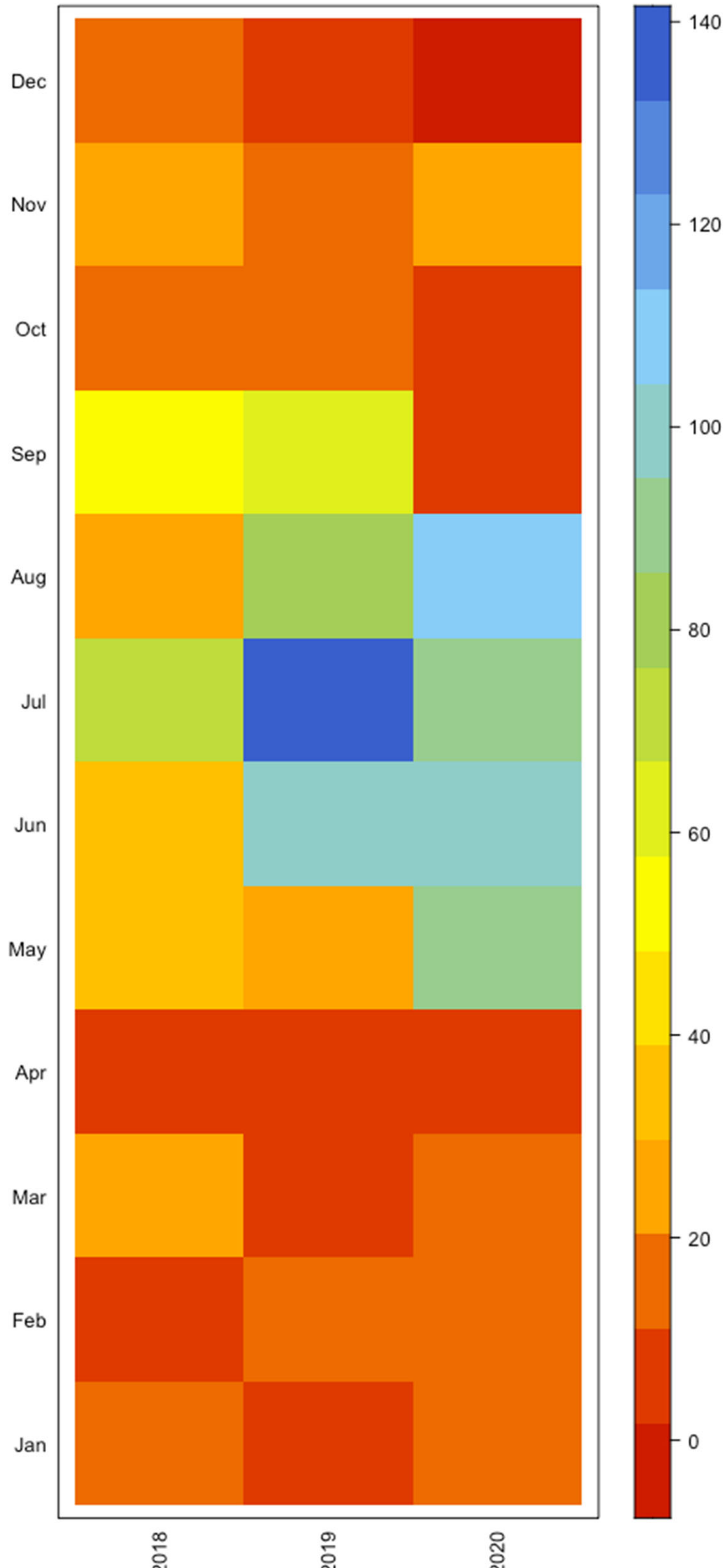

Fig. 2 Monthly precipitation values (mm) from the Camrose Weather Station for 2018, 2019, and 2020. Warmer colours indicate months with low precipitation values, while warmer colours indicate months with higher precipitation values

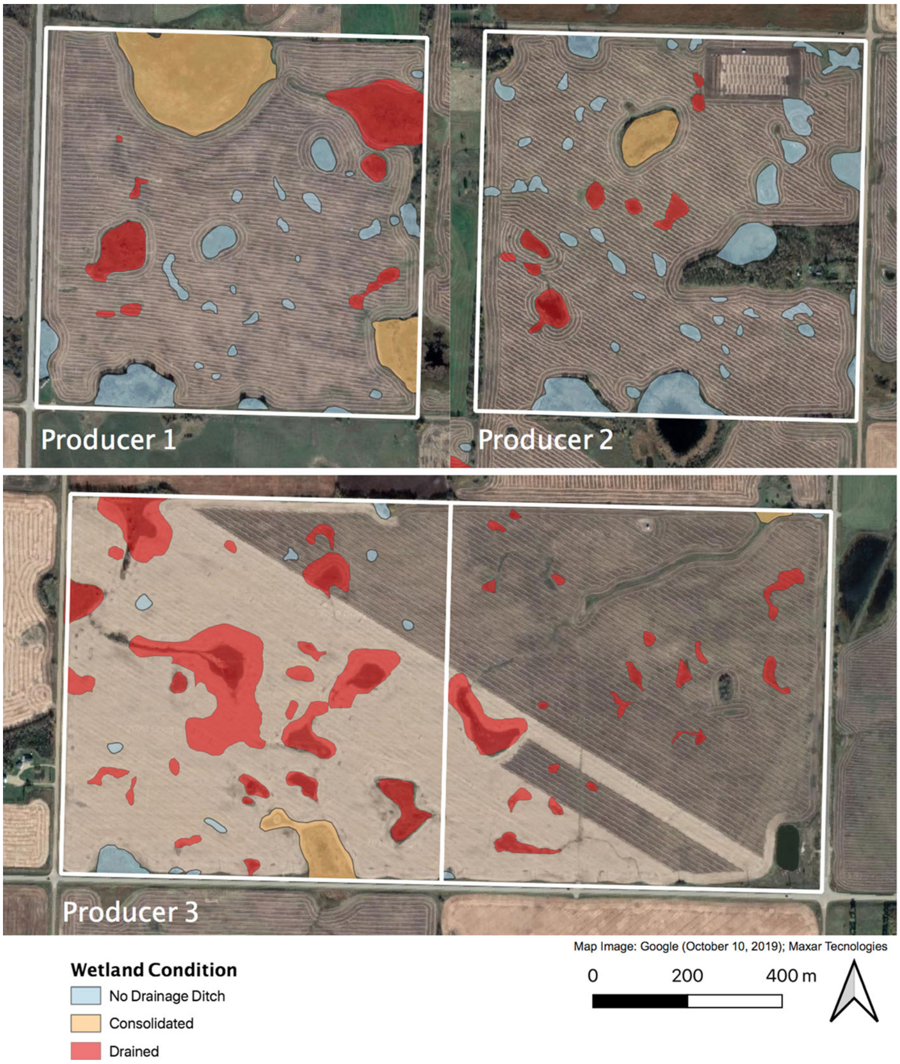

Fig. 3 Location and status of wetland basins in each of the four quarter sections included in the study

wetland management within this specific field or across their operation, producers indicated that the results would not dissuade them from continuing to drain surface water from wetlands, or change their practices with respect to seeding and cultivating within or adjacent to wetland basins. While the producers generally expressed the opinion that wet areas are financially risky and can produce lower yields, there was still a general sense that draining and consolidating wetlands as a management practice leads to higher productivity on average and over the longer term, despite an acknowledgement that the increasingly unpredictable weather has elevated the risk and uncertainty of cultivating within or near a wetland.

The apparent desire of each producer to maintain the status quo with respect to wetland management seems counterintuitive, as a rational business producer could be expected to alter their practices when faced with data indicating a financial loss (Soukup et al. 2015); however, it is consistent with behavioral economic theory, where rational choices include both the measurable (i.e., financial) and non-measurable (i.e., social) dimensions that influence decision-making (Cartwright 2018). Unmeasured factors, such as future expectation of increased yields, perceived spread of weeds, increasing value of time in uncertain

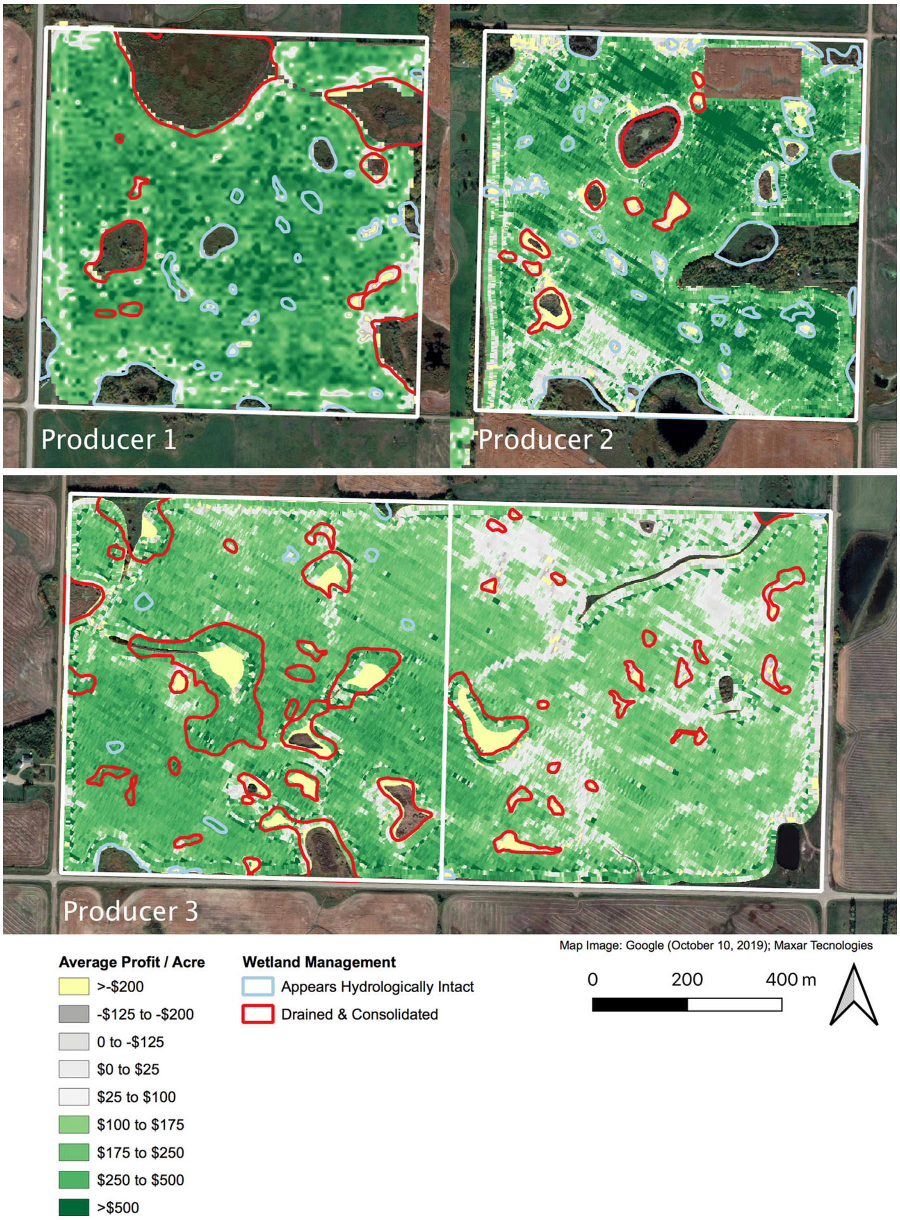

Fig. 4 A comparison of field level profit and loss within each quarter section included in the study

weather conditions, productivist mentality, and local socio-cultural farming traditions may all be factors that contribute to the attitudes and decisions of the producers who participated in our study. For example, one of the producers noted that despite the unfavorably wet growing conditions in the summer of 2019, many of the small wetlands in his field still showed a profit, and he expected that these areas would yield a much bigger profit in a drier year. This optimism for realizing future profit was a common sentiment, with all of the producers expressing a willingness to take the financial risk of cultivating through or near a wetland each year, on the hope that favorable weather would result in even a small profit. Such optimism is characteristic of the social and personal factors that drive this decision.

The risk of financial loss associated with wetland drainage is also balanced against the nuisance costs of

Table 3 Average profit associated with wetland and non-wetland areas for each agricultural operation

	Cultivated area (Acres)	Total profit ($)	Range of profit ($)	Average profit/acre ($)
Drained + cultivated basins				
Producer 1 (n = 10)	3.9	135.99	− 37.84 to 65.06	34.60
Producer 2 (n = 10)	2.8	− 408.33	− 174.39 to 11.10	− 145.31
Producer 3 (n = 44)	31.3	2381.03	− 179.59 to 1838.43	76.12
Total	38.0	2108.69	–	55.46
Hydrologically intact basins				
Producer 1 (n = 25)	2.6	533.73	− 18.88 to 116.96	202.17
Producer 2 (n = 39)	6.6	236.85	− 33.52 to 121.52	35.83
Producer 3 (n = 12)	1.2	181.26	− 17.53 to 63.42	148.85
Total	10.4	951.84	–	90.91

driving around, rather than through, a wetland, which can decrease operational efficiency and result in financial losses attributed to lost time, soil compaction, and input overlap (Cortus et al. 2009). Ultimately, by draining wetlands, producers strive to increase operational efficiency at the field level; however, many of the drained wetlands in these fields were too wet to seed in the spring, as evidenced by the areas of “no data” in the profit and loss map. This suggests that wetland drainage may not always reduce the “endless turning” and result in the operational efficiency that producers strive for by adopting this management practice.

The fact that these producers are not dissuaded from maintaining the status quo with respect to how surface water and wetlands are managed within these fields, despite the clear risk of reduced profitability or even a financial loss, is an important consideration for policy makers. In many jurisdictions, financial incentives are being explored and/or used to change producer behaviour and drive improvements in wetland management outcomes; however, the results from this study suggest that operational decision-making may override purely financial incentives. The producers in our study clearly communicated that field-level operational efficiency was a strong consideration in their decision-making, and this result has been documented by other scholars (Liu et al. 2018). Consequently, field-level efficiency must be seriously considered in the design of both programs and policies that aim to conserve or restore wetland habitat, and data from sub-field profitability mapping can help to inform this discussion. For example, in our study Producer 3 had a single drained wetland basin that accounted for 77% of the revenue for all drained and consolidated basins, and when this single basin is removed from the sample, the average profit/acre for drained and consolidated basins drops from $76.11 to $24.81 (Table 6). In a jurisdiction like Alberta, where agricultural producers are actively being sought out and paid to restore drained wetlands, this type of information could be used to identify wetland basins with good returns, as well as basins that consistently yield a financial loss or lower than desired profits. If these low-yielding basins are located in portions of the field where wetland restoration would not substantially reduce operational efficiency, producers may be willing to accept a financial payment to restore the basin. By carefully planning and targeting low-yielding basins for restoration, there are opportunities to improve financial outcomes for producers, while also contributing to environmental policy goals.

Notably, effective conservation policy is not driven by environmental or financial arguments alone (Liu et al. 2018). The attitudes and preferences that individual crop producers have with regard to retaining or restoring wetlands in working crop landscapes is integral to decision-making (Sweikert and Gigliotti 2018). For example, even if a financial argument exists for retaining wetlands, some producers consider wetlands to be aesthetically displeasing, others may be concerned about wetlands as a sources of weeds or

Table 4 Basin-level summary for all wetlands identified for Producer 1

Basin area (acres)	Cultivated area within basin (acres)	Proportion of basin cultivated (%)	Total basin profit ($)	Average profit/acre ($)
Drained + consolidated				
0.66	0.66	100	− 37.87	− 56.96
0.58	0.30	51	− 13.73	− 45.83
2.88	0.32	11	− 9.55	− 29.48
5.31	1.04	20	7.18	6.92
2.45	0.26	11	10.08	38.87
13.19	0.75	6	31.09	41.31
0.19	0.19	100	24.82	131.03
0.24	0.24	100	65.06	269.64
0.12	0.12	100	41.37	352.09
0.04	0.04	100	17.54	442.22
25.66	**3.93**	**15**	**135.99**	**34.64**
Hydrologically intact				
Ephemeral				
0.08	0.08	100	− 18.88	− 239.85
0.30	0.30	100	3.36	11.27
0.04	0.04	100	0.92	24.50
0.09	0.09	100	3.03	31.87
0.09	0.09	100	6.51	75.28
0.11	0.11	100	14.81	129.07
0.13	0.13	100	18.86	141.97
0.05	0.05	100	7.31	162.12
0.05	0.05	100	17.44	331.83
0.12	0.12	100	48.02	407.43
0.11	0.11	100	44.25	409.97
0.06	0.06	100	25.40	450.77
0.03	0.03	100	16.17	501.46
Temporary				
0.53	0.09	17	− 7.83	− 85.15
0.67	0.08	12	− 6.27	− 77.86
0.19	0.03	17	0.14	4.10
0.09	0.04	44	4.76	123.43
0.85	0.07	8	14.68	203.00
0.13	0.13	100	34.39	256.33
0.46	0.39	84	114.03	291.79
0.31	0.02	6	5.69	310.11
0.11	0.11	100	45.99	412.42
0.28	0.28	100	116.96	420.08
Semi–permanent and permanent				
2.92	0.04	1	2.53	66.04
0.80	0.09	12	21.46	226.16
8.60	**2.64**	**31**	**533.73**	**202.28**

Bold values indicate totals for each wetland management category (Drained + consolidated and Hydrologically intact)

Table 5 Basin-level summary for all wetlands identified for Producer 2

Basin area (acres)	Cultivated area within basin (acres)	Proportion of basin cultivated (%)	Total basin profit ($)	Average profit/acre ($)
Drained + consolidated				
1.19	0.79	66	− 174.39	− 221.89
0.45	0.36	80	− 76.08	− 211.59
0.42	0.15	37	− 30.88	− 201.40
0.17	0.17	100	− 24.27	− 141.51
0.11	0.11	100	− 13.32	− 119.86
0.64	0.64	100	− 69.43	− 108.29
0.23	0.23	100	− 23.78	− 101.62
2.38	0.01	0	− 0.61	− 63.16
0.22	0.21	99	− 7.29	− 34.24
0.13	0.13	100	11.10	85.03
5.94	**2.81**	**47**	**− 408.95**	**− 145.54**
Hydrologically intact				
Ephemeral				
0.20	0.13	64	− 33.52	− 259.83
0.15	0.11	76	− 27.52	− 244.41
0.10	0.10	100	− 18.62	− 187.41
0.63	0.14	23	− 25.32	− 178.35
0.15	0.14	98	− 24.54	− 169.66
0.08	0.08	100	− 10.96	− 138.32
0.10	0.10	100	− 11.59	− 110.94
0.19	0.19	100	− 19.12	− 98.48
0.27	0.27	100	− 22.85	− 84.13
0.33	0.33	100	− 22.26	− 67.84
0.23	0.23	100	− 14.86	− 64.68
0.18	0.18	100	− 4.66	− 26.43
0.06	0.06	100	− 0.70	− 11.23
0.19	0.19	100	− 1.26	− 6.71
0.93	0.88	94	12.75	14.51
0.25	0.25	100	8.09	32.63
0.11	0.11	100	5.71	50.71
0.29	0.29	100	15.39	53.48
0.07	0.07	100	5.46	72.86
0.19	0.19	100	21.74	112.38
0.12	0.12	100	21.99	184.91
0.17	0.17	100	34.92	204.34
0.13	0.13	100	27.45	210.72
0.09	0.09	100	18.98	220.89
0.10	0.10	100	23.93	246.29
0.06	0.06	100	14.76	253.10
0.14	0.14	100	35.84	261.10
0.33	0.34	100	121.52	362.26
0.11	0.11	100	48.88	462.99

Table 5 continued

Basin area (acres)	Cultivated area within basin (acres)	Proportion of basin cultivated (%)	Total basin profit ($)	Average profit/acre ($)
Temporary				
0.15	0.03	18	− 2.13	− 82.44
0.30	0.001	0.5	− 0.10	− 74.77
0.84	0.49	59	21.53	43.81
0.50	0.34	68	19.76	58.01
0.15	0.02	16	6.87	300.55
Seasonal				
1.20	0.10	8	0.98	9.88
0.82	0.01	2	0.14	11.04
2.51	0.19	7	3.76	19.98
1.92	0.06	3	13.23	237.62
Semi–permanent and permanent				
3.05	0.08	3	− 6.84	− 86.84
17.37	**6.61**	**38**	**236.85**	**35.81**

Bold values indicate totals for each wetland management category (Drained + consolidated and Hydrologically intact)

salinization, while still others may feel it is the mark of a "bad" farmer to not cultivate every part of their property. There may also be pressure against doing things that are perceived by the larger community as being "different", thereby exposing producers to questions and critiques from neighbors (Sweikert and Gigliotti 2018). Finally, while this study focuses on the financial returns of canola production, it also highlights the distinction between the financial (profit) and economic (profit +) considerations of agricultural producers, and the challenge of integrating individual and societal economic values into decision making. A deeper understanding of this distinction and the underlying decision-making drivers is essential for building public trust and creating effective policy.

Study limitations and research needs

While our analysis of revenue was done at the sub-field scale, we used average field-level cost data because our producer partners are not consistently using variable rate application of inputs due to prohibitive equipment costs and fees to agricultural consulting companies. In order to derive more precise calculations of sub-field profitability, input costs should also be derived at the sub-field scale; however, this can only be done if producers are utilizing equipment for variable rate input application. This study also only included a single growing season of data, and while modeling agricultural profitability from a single year provides an informative snapshot of sub-field profitability, agricultural producers financially plan several years into the future to ensure viable income streams. Consequently, including profitability data from multiple years, and from across a range of climatic conditions, would provide a much stronger understanding of how wetland management practices influence field-level productivity and profitability. Further, this study included a small number of producers, casting some doubt on whether the views expressed by these producers are representative of those held by the larger agricultural community in Alberta, or elsewhere, given that many other studies have shown that different communities and individual producers can have unique views on and preference

Table 6 Basin-level summary for all wetlands identified for Producer 3

Basin area (acres)	Cultivated area within basin (acres)	Proportion of basin cultivated (%)	Total basin profit ($)	Average profit/acre ($)
Drained + consolidated				
1.65	0.62	38	− 179.59	− 288.06
0.29	0.29	100	− 73.56	− 255.86
0.14	0.14	100	− 28.72	− 211.07
0.07	0.07	100	− 13.94	− 206.08
0.17	0.17	100	− 29.19	− 167.95
0.70	0.70	100	− 114.96	− 164.51
0.58	0.58	100	− 78.74	− 136.46
0.26	0.26	100	− 35.38	− 136.23
1.36	0.19	14	− 25.91	− 136.22
0.08	0.08	100	− 9.86	− 122.66
0.44	0.44	100	− 53.07	− 121.88
0.44	0.35	78	− 35.37	− 102.13
0.08	0.08	100	− 8.28	− 98.24
0.19	0.19	100	− 15.52	− 82.39
0.29	0.29	100	− 20.56	− 70.35
0.07	0.07	100	− 4.06	− 60.46
0.14	0.14	100	− 6.03	− 42.48
0.09	0.09	100	− 2.49	− 27.40
0.34	0.05	14	− 1.25	− 25.38
0.19	0.20	100	− 3.21	− 16.44
3.10	3.10	100	− 45.59	− 14.69
1.53	1.53	100	− 5.55	3.63
3.45	1.36	39	− 4.22	− 3.11
0.28	0.28	100	− 0.08	− 0.29
0.75	0.75	100	12.33	16.53
0.37	0.37	100	10.81	29.30
1.71	1.36	80	59.41	43.56
0.11	0.11	100	6.31	59.10
0.21	0.21	100	13.14	2.47
2.68	2.66	99	269.18	101.33
0.12	0.12	100	13.39	114.42
0.15	0.15	99	16.99	115.22
3.61	2.27	63	295.63	130.12
0.15	0.15	100	21.64	140.42
0.28	0.28	100	45.98	166.25
0.21	0.21	100	36.79	172.15
9.70	9.42	97	1838.43	195.27
0.63	0.63	100	145.97	229.97
0.17	0.17	100	46.11	265.62
0.36	0.36	100	97.73	269.73
0.15	0.15	100	43.30	286.58
0.16	0.16	100	48.47	295.16
0.35	0.35	100	105.23	296.70

Table 6 continued

Basin area (acres)	Cultivated area within basin (acres)	Proportion of basin cultivated (%)	Total basin profit ($)	Average profit/acre ($)
0.14	0.14	100	49.34	341.06
37.96	**31.28**	**82**	**2381.03**	**76.11**
Hydrologically intact				
Ephemeral				
0.08	0.06	76	− 4.71	− 81.74
0.08	0.03	44	− 0.42	− 12.30
0.13	0.13	100	12.09	93.79
0.10	0.10	100	15.38	153.14
0.12	0.12	100	18.31	158.45
0.14	0.14	100	41.17	303.63
0.16	0.16	100	49.55	308.39
0.20	0.20	100	63.42	315.41
Temporary				
0.06	0.03	49	− 6.25	− 205.76
0.10	0.09	98	− 17.53	− 185.24
1.22	0.08	7	1.96	23.37
0.25	0.08	31	8.28	110.24
2.62	**1.22**	**46**	**181.26**	**148.85**

for conservation (Addo et al. 2017; Fergen et al. 2018; Zimmerman et al. 2019). Despite these limitations, the results of this study indicate that the use of wetland drainage and consolidation as a preferred management practice in cropland does not always produce a financial benefit.

In order to improve our understanding of the magnitude of the financial benefits or losses associated with wetland drainage practices, there are a number of questions and considerations for future research into sub-field productivity. First, expanding the economic model to include fixed drainage costs, nuisance costs, and sub-field level input costs would allow for a more precise calculation of profit. Second, exploring how profit and loss within drained basins fluctuates over multiple growing seasons will provide a clearer picture of how the practice of drainage influences longer-term financial outcomes, and whether losses in one year can be offset by profits in other years. Further understanding how the physical properties of wetlands, such as size, depth, and slope influence profitability may also provide useful information about which wetlands, if drained, are more likely to result in a financial loss. Finally, including a larger number of producers in the study, with a more robust analysis of producer views and attitudes about wetland drainage, profitability, and production decisions, would contribute to a better understanding of how to design wetland incentive frameworks and programs for producers in the crop sector.

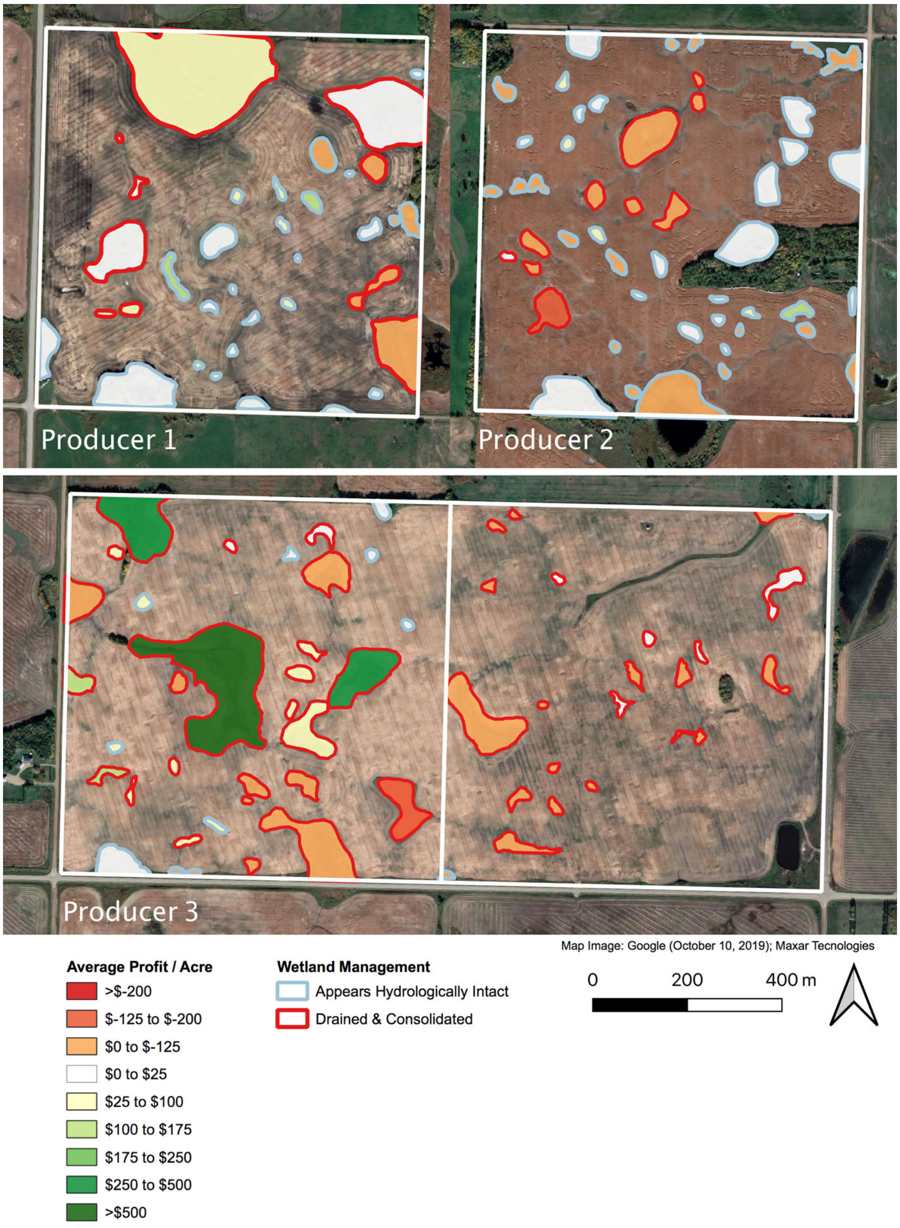

Fig. 5 Average profit per acre for each individual wetland basin

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Author contributions SC conceived of the project, lead the development of the research design, obtained funding, participated in data analysis, and led the writing of the manuscript. BD and SK were involved in site selection, data collection, data analysis, and contributed to the manuscript. JPW recruited study participants, conducted the economic analysis, and contributed to the manuscript.

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Compliance wih ethical standards

Conflict of interest All authors declare that they have no conflict of interest or financial ties to disclose.

Informed consent All participants were provided with an information sheet about the study that identified the lead researchers, provided background on the study, identified the purpose and methods that would be employed, listed the benefits and risks of participating, stated that all information would be confidential and that participants would remain anonymous, outlined how the information provided by producers would be used in technical reports and academic articles, and explained that participants could withdraw from the study at any time. Written consent to participate in the study was obtained from every participant prior to initiating the study.

Consent to publish Participants were informed that the results of the study would be summarized and presented in technical reports and academic journal articles, and written consent to publish this information was obtained from each participant prior to initiating the study.

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