Crop Rotations and Changes in Saskatchewan Fertilizer Use: 1991-94 and 2016-19

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Abstract

CONTEXT

Dryland crop production in the Canadian prairies has significantly changed over the past 30 years. This is particularly true for the province of Saskatchewan, which accounts for over 40% of all the productive crop land in Canada. In the early 1990s, Saskatchewan farmers frequently fallowed their fields for an entire growing season, using tillage as their leading method of weed control. The commercialization of herbicide tolerant canola in 1995 was a transformative innovation as farmers were able to annually get efficient weed control through herbicide tolerant canola production, resulting in the transition of millions of acres of summerfallow into continuous crop rotations. A second change, increased production of nitrogen fixing pulse crops, also occurred.

OBJECTIVES

The objective is to assess the impact that increased production of nitrogen fixing pulse and lentil crops has had in terms of fertilizer use and that rapid adoption of genetically modified, herbicide tolerant (GMHT) canola has had on fertilizer use.

METHODS

To answer the objectives, this article analyzes the responses to a Saskatchewan crop farmer online survey collected from November 2020 to April 2021. The survey was distributed and administered by the Canadian Hub for Applied and Social Research at the University of Saskatchewan.

RESULTS

Results indicate positive impacts of pulses across the two crop rotation periods, but the extent at which the inclusion of pulses has affected the N fertilizer requirements and the increase in the yield of the subsequent crop is different. Additionally, farmers applied fewer pounds of nitrogen, phosphorus and potassium fertilizer per bushel of GMHT canola yield during the 2016-19 period compared to conventional canola during the 1991-94 period.

CONCLUSIONS

As pressure to improve the environmental sustainability of agricultural production continues to mount, the results of this research highlight how grain farmers on the Canadian prairies are using fertilizer more efficiently, resulting in lower rates applied per bushel of grain yield. Both the inclusion of pulses in a crop rotation and adoption of GMHT canola varieties have contributed to improved fertilizer use efficiency.

IMPLICATIONS

Focusing on further expansion of the pulse crop industry on the prairies could help to improve the environmental footprint of prairie agriculture while maintaining or even boosting production levels.

Key words: conventional canola, GMHT canola, land use change, nitrogen, pulses, yield

1. Introduction

Technology changes and innovations have transformed crop production on the Canadian prairies over the past 30 years. Farmers no longer rely on summerfallow as their leading form of weed control due to the innovation of herbicide tolerant crops, particularly canola (Brassica napus L.). Changes in seeding equipment such as variable rate application and precision seeding have impacted the input of both seed and fertilizer. The commercialization of innovative products and technologies are the principle drivers of improved agriculture sustainability (Sutherland et al. 2021).

Sustainability has become an increasingly important cornerstone of both agricultural and environmental policy. Multiple international agreements and protocols are leading aspects of international environmental policy setting. The Convention on Biological Diversity, the Cartagena Protocol on Biosafety and the Paris Climate Accord are but three examples. These international agreements, taken in combination with various regional initiatives, are driving 21st century mandates calling for reduced environmental impacts from agriculture, especially crop production and the use of crop protection inputs such as chemicals and fertilizers. The concern for crop production agriculture is the lack of empirical evidence underpinning the various environmental mandates. As an example, the European Union's Farm to Fork Strategy calls for a

50% reduction in pesticide use, a 20% reduction in fertilizer use and a tripling of organic crop production, none of which are based on, or supported by, empirical evidence (Wesseler 2022).

Within a similar policy parameter, Environment and Climate Change Canada (ECCC) announced that a 30% reduction mandate for nitrous oxide emissions from fertilizer use would be a priority for Canada's environmental policy framework (ECCC 2022). This emission reduction target is to be reached by 2030 and to be based on 2020 emission levels. This mandate lacked any reference which could be used to empirically justify the reduction target of 30%. When this mandate was initially announced, the federal government indicated it would be a mandatory target. However, backlash from the agriculture industry quickly resulted in the federal government publicly confirming that the 30% emission reduction would be a voluntary target (Baumgarten 2022). The rapid pivot by the federal government from mandatory to voluntary highlights the challenges of not empirically grounding environmental targets and mandates.

Empirical evidence is not readily available that is capable of providing accurate and up-to-date perspectives of agricultural input use. The lack of reliable data is a fundamental challenge for the ECCC 30 % emission reduction target as quantifying on farm fertilizer emissions poses significant challenges in the ability to measure changes. This article utilizes data gathered through an extensive survey of crop producing farmers in Saskatchewan. The objective of this article is twofold: first, to assess what impact the increased production of nitrogen fixing pulse and lentil crops had, in terms of fertilizer use; and second what impact the rapid adoption of genetically modified, herbicide tolerant (GMHT) canola had on fertilizer use.

2. Background

As the global population is predicted to rise to 9.7 billion in 2050 and 10.4 billion by 2100, global food demand is set to soar (UN 2022). This puts unprecedented pressure on Canadian agriculture to produce sufficient foods as a key supplier of crops like wheat, canola and pulses. In order to meet growing domestic and international consumer demand, producers are using high amounts of fertilizer and pesticide inputs in crop production (Zhang et al. 2015), which is logical given the increased amount of land in continuous crop production now that millions of acres of summerfallow have been removed from crop rotations. While this approach increases crop yields (Hauggaard-Nielsen et al. 2016), it also can have negative consequences on the environment (Seitzinger & Phillips 2017), with the potential to pollute soil, air and water. Moreover, high and unpredictable fertilizer costs in Western Canada have generated interest in alternative nitrogen sources.

An alternative sustainable approach is to use annual pulse crops such as lentil, dry pea and chickpea in crop rotations to achieve the goal of increasing subsequent crop yields (St. Luce et al. 2015) while minimizing environmental impacts (Gan et al. 2015) and reducing nitrogen fertilizer costs up to 37% (Khakbazan et al. 2022). Pulses are well known for their significant role in nitrogen (N) cycling as they have the ability to fix atmospheric nitrogen through symbiosis (Hossain et al. 2016). Nitrogen fixation is defined as the process by which nitrogen is taken from its molecular form (N_2) in the atmosphere and converted into nitrogen compounds useful for other biochemical processes. Fixation can occur through atmospheric (lightning), industrial or biological processes (Hanrahan and Chan 2005). Schoneau (2016) reports that in pulse crops, about 50 to 80% of N comes from the atmosphere through biological fixation in nodules that form on the pulse crop roots. However, the exact amount of the N benefit (or N credit) varies depending on a series of additional factors (Fleury 2016) including soil and environmental conditions, the success of nodulation, available nitrogen and other nutrients.

Because pulses produce N through fixation, they can increase soil residual and mineralizable N (Fleury 2016), thus reducing the need for N fertilizer in subsequent crops. In addition to the increase of soil available nitrogen, including pulses in a crop rotation is shown to improve soil moisture reserves in deeper soil depths, enhance soil microbiology and soil health and increase yield of a subsequent crop (Gan et al. 2015; Hossain et al. 2016; Liu et al. 2020; Wright 1990). The biggest benefits can be seen in the crop following pulses; however, some benefits may carry over to the second year, but to a lesser degree (Chorney 2020).

Results of various research studies conducted in Canada, while varying, suggest that pulses contribute to reducing the need for N supply of crops grown in the consecutive crop rotation year (Chen 2016; MacWilliam et al. 2014; St. Luce et al. 2015). Khakbazan et al. (2014) found that including pulses in crop rotations was the most profitable because of both the positive contribution to the yield of the subsequent crop and the reduction of the amount of nitrogen applied the following year. Generally, the net return was maximized between 60 and 90 kilograms per hectare or between 53 and 80 pounds per acre of nitrogen applied.

Over the past three decades, pulse crops have become significant in Canadian agriculture and have generated an estimated annual market value of C$2.7 billion during 2019-2020 (AAFC 2021). For the crop year 2021 - 2022, Canadian production of pulses and special crops reached 6.6 million tonnes (AAFC 2022a), increasing from 1 million tonnes in the early 1990s (AAFC 2005).

Saskatchewan is at the heart of the Canadian pulse industry, accounting for the largest pulse crop area in Canada (Statistics Canada 2022a). With approximately 15,000 pulse growers in

2014, Saskatchewan farmers grew 95% of Canada's lentils, 99% of its chickpeas, and 64% of its dry peas crop (Phillips and Fransoo 2022). In 2016, Western Canadian farmers planted a record pulse crop, an estimated 5.14 million acres to lentils and 4.28 million acres to peas, up 30% and 16% year-over-year respectively. The province is the world's leading exporter of dry peas and lentils, with a 65% share of world lentil exports and 55% share of world pea exports (Saskatchewan Advantage 2021). Production of dry peas and lentils in 2021 were 56% and 44% lower than in 2020, respectively, due to significant drought (Figure 1 and 2) but Saskatchewan still remained the main pulse producer in Canada.

Figure 1: Sask annual dry pea production

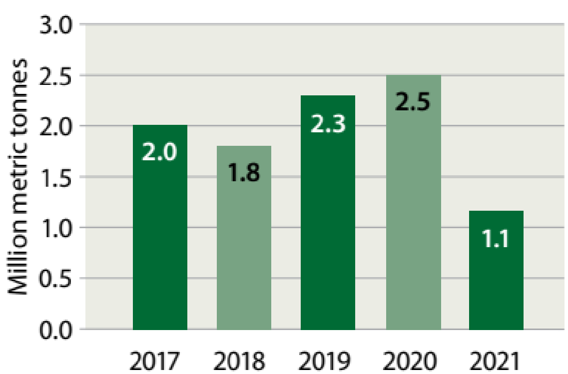
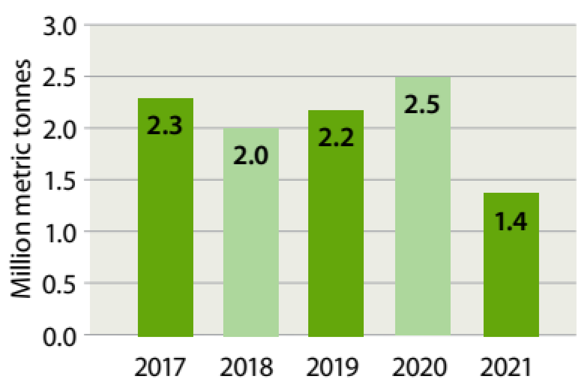


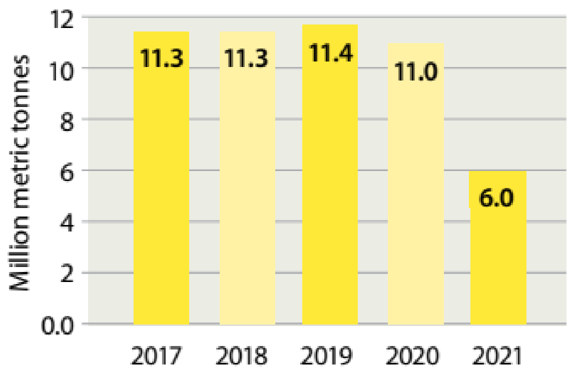
Figure 2: Sask annual lentil production



Source: Saskatchewan advantage, 2021.

In addition to pulses, Saskatchewan is considered the world's leading exporter of canola seed, accounting for 19% of global canola seed exports in 2021 (Figure 3). The extensive drought in the Canadian prairies in 2021 had a significantly negative impact on yields in 2021.

Figure 3: Sask annual canola seed production



Source: Saskatchewan Advantage, 2021.

Canola was first developed in the Canadian prairies during the 1960s and 1970s to address dependence on imported edible oils. Since genetically modified, herbicide tolerant (GMHT) canola became commercially available to farmers in 1995, Canadian production has roughly tripled, reaching approximately 19.5 million tonnes in the 2020-2021 crop year (AAFC 2022b). Canadian canola production is concentrated in the provinces of Saskatchewan, Alberta and Manitoba, which account for 99% of Canadian production by tonnage.

Among several factors that help explain the increase in yield and seeded canola acreage in Canada, the development of GMHT varieties is considered to be one of the most influential ones (Stringam et al. 2003). Unrestricted commercial production began in 1997 and the subsequent adoption was rapid, reaching 25% in the initial year, 84% by 2002, and 98% by 2007 (Gusta et al. 2011). Total canola acreage significantly increased as well, rising 31% to an average of 13.9 million acres (5.6 million hectares) from 2003-2008, up from an average of 10.5 million acres (4.2 million hectares) from 1991-1995 (Statistics Canada 2008).

One of the most important benefits of GMHT canola when compared to conventional canola is reduced tillage requirements to improve weed control (Shaw 2014). As a result, GMHT canola has also reduced soil erosion and increased levels of moisture conservation by 86% and 85%, respectively (Gusta et al. 2011). Equally important is the impact of GMHT canola adoption on the increase in average yields and in efficiency of input use between 1990 and 2010 (MacWilliam et al. 2016). However, the large-scale application of HT crops has raised concerns on the potential risk of increased weed resistance to pesticides due to intensive use of the same ingredient and the impact that it might have on biodiversity (Beckie et al. 2013; Mortensen et al. 2012).

3. Methodology

This article analyzes the responses to a Saskatchewan crop farmer online survey collected from November 2020 to April 2021. The survey was distributed and administered by the Canadian Hub for Applied and Social Research at the University of Saskatchewan. The survey was granted exemption from ethics approval by the University of Saskatchewan's Research Ethics Board, as it only collects data.

The results focus on the analysis of responses about fertilizer use for cereal, pulses and oilseed crops during the 1991-1994 and 2016-2019 four-year crop rotation periods. On average, it took three to five hours to complete the survey, at the end of which participants received up to $200 in compensation. They were asked to complete the survey for a single field, as long as it was used for the production of conventional, genetically modified or organic crops. When possible, participants were asked to report on the same field for both the 1991-1994 and 2016-2019 time periods.

This analysis examines the impact the inclusion of pulses in the four-year crop rotation had on the fertilizer needs of the subsequent crop and the impact of GMHT canola on fertilizer use. It additionally investigates the relationship (if any) between pulse crops and the yield of subsequent crops, and how rates of application of elemental fertilizer components for pulses compare to cereals and oilseeds (canola). Participants were asked to report the type of crop (cereal, oilseed, pulses) and the variety they planted for each crop year, the crop yields, total fertilizer applications in pounds per acre and nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) components for each fertilizer application pass from pre-seed, seeding, in-crop, to post-harvest. Respondents were asked these questions for multiple passes for each of pre-seed, seeding, in-crop and post-harvest applications. However, only responses on the first application pass are counted toward the derived values, because responses on second and third pass were limited (e.g., one response on N %age for pre-seed in 1991) or no responses were provided at all.

Statistical tests were applied to ensure a rigorous examination of the dataset, enabling for informed conclusions from the survey results. The analysis focused on understanding the dynamics of fertilizer use and its effects across cereals, pulses and oilseed crops during the 1991-1994 and 2016-2019 four-year crop rotation periods. Descriptive statistics are used to understand the distribution of key metrics across different crop types and rotation periods, which involved calculating measures such as mean, median and range for each dataset. Starting with the pulses impact on subsequent crop's nitrogen rate, t-tests were employed to determine if the difference in nitrogen rates between the two rotation periods were statistically significant. This provided oversight into the influence of pulses on the nitrogen requirements of the following non-pulse crop.

As part of assessing the impact of preceding pulse crops on cereal yields, t-tests were again applied to compare yields after the cultivation of pulses versus non-pulse crops for both crop rotation periods. This analysis offered an understanding of how the inclusion of pulses in a crop rotation influenced the yield of subsequent cereal crops.

When examining the change in elemental fertilizer components for pulses, the elemental fertilizer components between the two periods were compared using t-tests. This helped in identifying significant shifts in the application of elemental fertilizer components for pulses over the years. To understand the NPKS requirements for pulses compared to other crops, a comparative ANOVA was performed. This method helped in contrasting the nitrogen, phosphorus, potassium and sulfur application rates of pulses against those of oilseeds and cereals for both rotation periods.

Lastly, t-tests were utilized for the analysis regarding changes in elemental fertilizer components for conventional canola and GMHT canola. This analysis aimed to discern the variations in fertilizer application practices between conventional canola and the GMHT canola over the two crop rotation periods.

Originally, the Saskatchewan farmer dataset included 160 participants, but for the purposes of this analysis, a subset consisting of 69 respondents is used. Data cleaning and analysis were performed using Excel and R software. Data cleaning process for both periods involved removing duplicate data, outliers[1], respondents that did not farm either in the 1991-94 or 2016-19 period, those with incomplete responses in terms of crop yield or crop types planted, incorrect responses, as well as duplicate data. It should be noted that the number of respondents that farmed in the 2016-19 period is greater than those who farmed in the 1991-94 period. However, to ensure a valid comparison of the estimates across the two periods, this analysis uses only the subsample that farmed in both periods. Additionally, a respondent would be excluded from the subset if associated with an amount of either N, P, K, S higher than the total fertilizer amount.

[1] In the datasets for both crop rotation periods outliers were identified as the observations with extremely high values of seedable acres and fertilizer rates.

Raw data was transformed and structured into a usable format for the analysis. Some responses required manual adjustments, such as nitrogen rates reported as a liquid fertilizer which required conversion into dry fertilizer rates. Some fertilizer rates were reported in kg/ha and were converted into lbs/acre, and crop yields reported in lbs/acre or tonnes/acre were converted into bu/acre.

Utilizing an online survey as the data-collection method facilitated the participation of demographically different participants across Saskatchewan, ensuring a representative sample. Most participants fall in the age category of 45 to 64 (61%) as compared to younger farmers (19%). In terms of education, 71% of farmers reported to have received post-secondary education compared to 19% who reported receiving a high school diploma. When asked if farmers collected off-farm income, 23% of participants responded 'yes'. In addition, a small percentage of respondents were farming total land bases smaller than 760 acres (10%). The majority of participants reported a farm size between 1,120 acres and 1,599 acres. Table 1 provides more detailed information on the demographics of the survey sample.

Table 1: Participant demographics

Fertilizer Survey	
Age	
18 to 24	3 %
25 to 34	7 %
35 to 44	9 %
45 to 54	23 %
55 to 64	38 %
64 to 74	14 %
75 and over	1 %
Education	
Post secondary education	71 %
High school diploma	19 %
No high school diploma	4 %
Prefer not to say	1 %

Collect off-farm income	
Yes	23 %
No	72 %
Farm Size	
Under 399 acres	4 %
400-759 acres	6 %
760-1,119 acres	16 %
1,120-1,599 acres	38 %
1,600-2,239 acres	14 %
2,240-2,879 acres	7 %
2,880-3,519 acres	3 %
3,520 acres or more	12 %

4. Results

With the simultaneous increase in pulse production in Saskatchewan and fertilizer costs, knowledge on the impact pulse crops have on fertilizer use is crucial to understanding how pulse production is beneficial to the environment and farm profitability. The percentage of respondents that included pulses at least once in their four-year crop rotation increased between 1991-94 and 2016-19 from 40% to 50%. Additionally, results indicate that in the 2016-19 period, farmers[2] started to slightly increase the frequency of pulses in crop rotation as a preceding crop to non-pulse crops.

The first step of the research was to quantify the positive impact diversification of crop rotations had on following non-pulse crop by reducing the nitrogen rate applied in pounds per bushel (Figure 4 and 5). Findings are consistent with what other long-term studies have shown. Inclusion of pulses in the crop rotation proved to be a good option, being followed by lower N application rates compared to other non-pulse crops. For the 1991-94 period, depending on the year in which the pulse crop is planted, the rate of nitrogen applied to the subsequent crop varies from 49% to 73% less than the rate applied when another crop (either oilseed or cereal) is

[2] Of farmers that have included pulses in the rotation, 17% have planted pulse crops twice in their four-year crop rotation period.

planted (Figure 4). For the 2016-19 period, nitrogen applied per bushel of crop varies within 3% - 19% less than what it was applied in the case when a pulse was not planted the year before (Figure 5).

Figure 4: Pulses impact on subsequent crop's nitrogen rate (1991-1994)

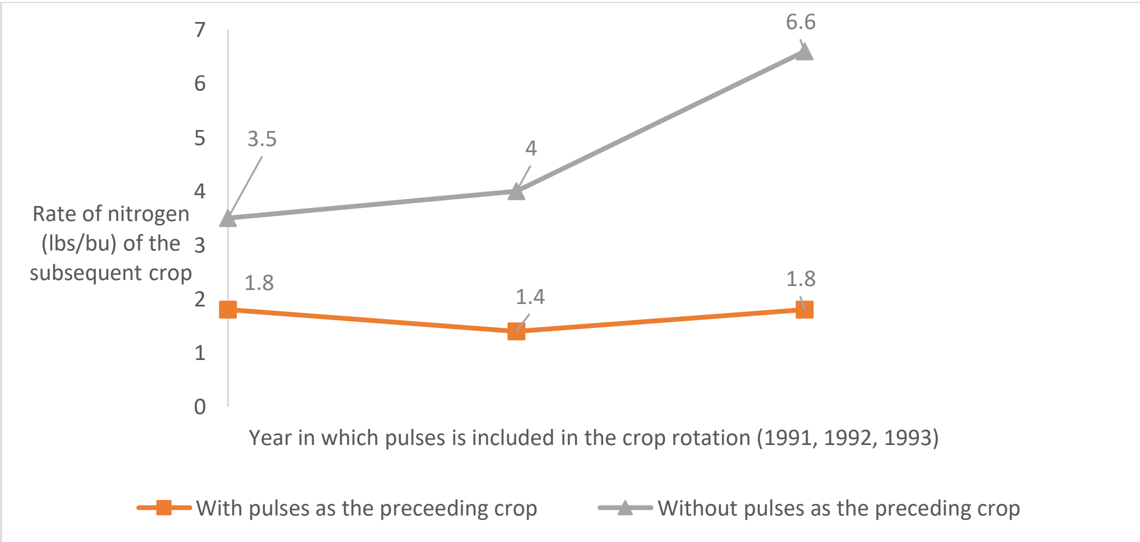
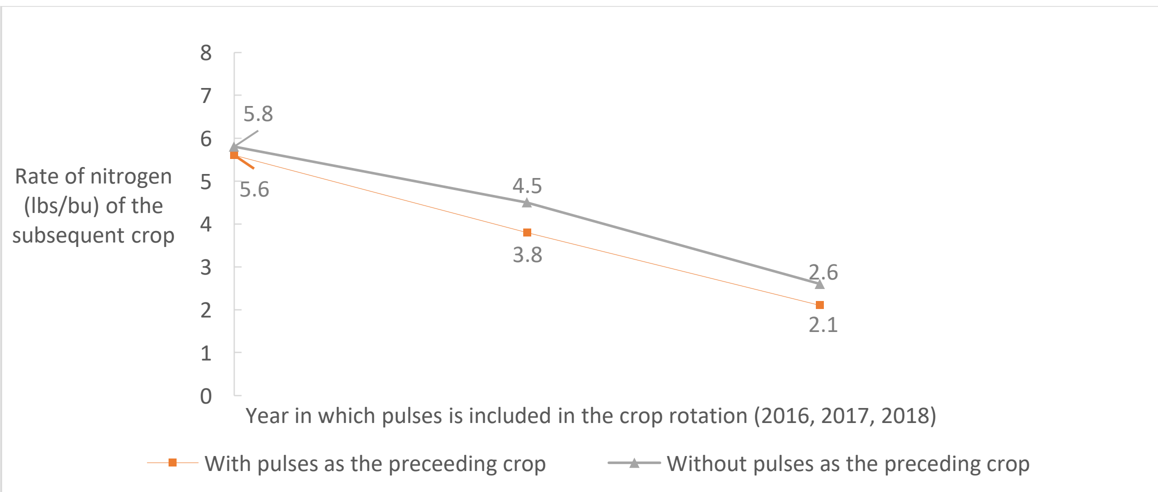


Figure 5: Pulses impact on subsequent crop's nitrogen rate (2016-2019)



A statistical test was conducted to ascertain the significance of the observed differences in nitrogen rates between the two periods. The resulting t-statistic was approximately 3.47. In this context, this value suggests that the observed difference in nitrogen rates is 3.47 times larger than what might be expected due to random chance alone. The associated p-value was approximately 0.074. While this p-value exceeds the conventional significance threshold of 0.05, it remains close enough to indicate potential merit in the observed difference. This result suggests that there might be a genuine difference in nitrogen rates between the two periods, even if it is not statistically significant at the conventional 0.05 level.

The empirical results highlight the importance of including pulses in crop rotations considering their ability to fix enough N for their own use and leave behind residual N for the next crop. From a farmer's perspective, this quantifiable information can assist in increasing on-farm profitability (greater yield of the subsequent crop) (Khakbazan et al. 2022) and reducing greenhouse gas (GHG) emissions (offset the N fertilizer requirements of a subsequent crop) (MacWilliam et al. 2018). Results indicate the same positive impact of pulses across the two crop rotation periods, but the extent at which the inclusion of pulses has affected the N fertilizer requirements of the subsequent crop is different.

Overall results also show an increase in the yield of the subsequent crop when a pulse crop is planted the year prior, with the exception of the 2018 crop yield (Table 2)[3]. Due to the low number of responses that followed a pulse crop with an oilseed or second pulse crop in their rotation, this portion of the analysis focuses on cereal crops that were preceded by pulse crops. For the 1991-94 period, the highest yield increase following a pulse crop is experienced in the 1994 crop year, while for the 2016-19 period, the highest positive impact is seen on the 2017 crop. It must be noted that although pulses are shown to contribute to the crop grown in the consecutive crop rotation year by reducing the need for nitrogen supply, the precise contribution of pulses is affected by

[3] Many parts of Saskatchewan experienced below-average rainfall levels in 2018, which may have contributed to the abnormal yield results.

various factors (i.e., available soil nitrogen, environmental conditions) and may vary by crop as well as over sites and crop years.

Table 2: Impact of preceding pulse crops on cereal crop yields (bu/ac)

	1992	**1993**	**1994**	**2017**	**2018**	**2019**
Yield with pulse as preceding crop	36 (2421)	51 (3430)	62 (4170)	88 (5918)	44 (2959)	66 (4439)
Yield without pulse as preceding crop	35 (2354)	46 (3094)	44 (2959)	52 (3497)	50 (3363)	63 (4237)
% difference	3%	12%	41%	69%	-11%	3%

Note: Brackets represent results as kg/ha.

A t-test was conducted to compare the cereal crops yields when preceded by a pulse crop and when not preceded by a pulse crop across the years. The resulting t-statistic was approximately 1.124 and the associated p-value for this test was about 0.287. Given this p-value, based on the data provided, as mentioned above, the evidence indicates a positive correlation between a preceding pulse crop and cereal crop yield, but it is not enough to conclude that there is significant impact on its yield.

Data was further analyzed to understand the change in elemental fertilizer components and yield for pulses across the two rotation periods. With the exception of potassium, the application of the fertilizer components (N, P, S) in pounds per bushel of crop yield (lbs/bu) experienced an increase in the 2016-19 period compared to the previous crop rotation. At the same time, the crop yield increased by almost 23% across the two periods (Table 3). Additionally, farmers were asked if the soil was tested for each crop year and, if so, if they saw an increase in soil fertility or not. For the 1991-94 period, farmers did not provide enough responses on soil sampling to be able to draw insight on this parameter. In the 2016-19 period, the majority of farmers who planted pulses (40% - 60%) sampled their soil, and most importantly, almost all of them (80% - 100%) noticed an increase in soil fertility.

The t-test yielded a t-test statistic of (-1.1415) and an associated p-value of 0.2704, which indicates the differences in elemental fertilizer components for pulses between the two periods are not statistically significant.

Table 3: Change in elemental fertilizer components for pulses

Crop rotation	Crop yield	Total N	Total P	Total K	Total S	N rate	P rate	K rate	S rate
1991-94	30.9± 3.5	35.3± 5.7	17.9± 2.7	37.8± 4.7	20± 2.5	1.1± 0.05	0.6± 0.05	1.2± 0.04	3.5± 0.1
2016-19	37.9± 4.5	191± 5.1	58.6± 2.3	20.9± 3.5	37.9± 3.5	4.7± 0.06	1.5± 0.04	0.5± 0.02	7.7± 0.1
Comparison	22.6%	441%	227%	- 44%	89%	327%	150%	-58%	120%

Note: Total NPKS amounts are reported in pounds per acre while NPKS rates are reported in pounds per bushel. The data in the table is presented as 'average ± half of the range' to provide a comprehensive overview of the central tendency and variability.

Due to the ability of pulse crops to fix nitrogen, it is expected that they are less reliant upon soil residual nitrogen compared with other crops (Kakraliya et al. 2018). In other words, science suggests pulses require less fertilizer than other crops. Our results reveal that pulses do require less or at least almost the same amounts of nitrogen and phosphorus applied, per bushel of crop yield, as oilseed and cereal crops (Table 4). This observation, along with the fact that the use of nitrogen fertilizer is a significant contributor to the overall carbon footprint of agriculture, (Pulse Sustainability n.d.) implies that pulses have a lower carbon footprint than other crops (Chai et al. 2021). Based on the ANOVA analysis for both crop rotations (1991-1994 and 2016-2019), the effect of different crop types (pulses, oilseed, cereal) on the NPKS rate is not statistically significant, with p-values of 0.538 and 0.465 respectively.

Table 4: NPKS requirements for pulses compared to other crops (lbs/bu)

Crop rotation	Crop	N rate	P rate	K rate	S rate
	Pulse	1.1 ± 1.8	0.6 ± 0.45	1.2 ± 0.35	3.5 ± 2.10

1991-94	Oilseed	5.96 ± 0.95	2.6 ± 0.4	1.18 ± 0.34	1.04 ± 0.13
	Cereal	3.5 ± 0.85	1.3 ± 0.05	0.68 ± 0.14	0.4 ± 0.20
2016-19	Pulse	4.7 ± 1.8	1.5 ± 0.45	0.5 ± 0.35	7.7 ± 2.10
	Oilseed	4.06 ± 0.95	1.8 ± 0.4	0.5 ± 0.34	1.3 ± 0.13
	Cereal	5.2 ± 0.85	1.4 ± 0.05	0.96 ± 0.14	0.8 ± 0.20

The data in the table is presented as 'average ± half of the range' to provide a comprehensive overview of the central tendency and variability.

Considering the recent substantive increases in canola acreage and changes to management practices for canola production in Saskatchewan, it is beneficial to investigate the resulting changes in fertilizer application. To understand how fertilizer application rates have changed when farmers switched from conventional canola to GMHT canola, responses were compared across the two crop rotation periods, as GMHT canola was not commercially available to farmers prior to 1995 and by 2016-19, the majority of canola acres in our dataset were seeded to GMHT varieties. Overall, findings suggest that farmers applied less pounds of nitrogen, phosphorus and potassium fertilizer per bushel of GMHT canola yield during the 2016-19 period compared to conventional canola during the 1991-94 period. Potassium experienced the highest decrease (58%), but nitrogen and phosphorus rates decreased significantly as well. Another important observation is the significant increase in GMHT canola yield compared to conventional canola which has nearly doubled in the second rotation period (Table 5). The t-test yielded a t-statistic of (-0.3444) and associated p-value of 0.7351, from which it can be inferred that the differences in elemental fertilizer components between conventional canola and GMHT canola across the two periods are not statistically significant.

Table 5: Change in elemental fertilizer components for conventional canola and GMHT canola

Crop rotation	Crop yield	Total N	Total P	Total K	Total S	N rate	P rate	K rate	S rate
1991-94	26.5 ± 4.1	160.5 ± 8.2	69.5 ± 6.3	32.1 ± 4.1	27.7 ± 3.1	5.96 ± 0.06	2.6 ± 0.05	1.2 ± 0.04	1.04 ± 0.02
2016-19	50.6 ± 7.2	182.3 ± 10.6	84.2 ± 8.9	22.6 ± 3.7	61.3 ± 3.7	4.06 ± 0.06	1.8 ± 0.04	0.5 ± 0.02	1.3 ± 0.04
Comparison	91%	14%	21%	-30%	121%	-32%	-31%	-58%	25%

Note: Total NPKS amounts are reported in pounds per acre while NPKS rates are reported in pounds per bushel. The data in the table is presented as 'average ± half of the range' to provide a comprehensive overview of the central tendency and variability.

5. Discussion

Innovation plays a key role in increasing the efficiency of agriculture. Results indicate that both innovations have had a positive impact on farmers, in terms of reduced fertilizer requirements. This provides an economic benefit for farmers as it reduces the fiscal resources allocated to the purchase of fertilizer and boosts yields. The economic gains made by farmers highlight the importance of economic sustainability.

Both crop innovations have made significant contributions to sustaining changes in land management practices. The expansion in the production of GMHT canola comes largely from the reduction in summerfallow acres. Crop rotations that included summerfallow as the leading form of weed control, required fewer fertilizer nutrient applications, but conversely suffered from increased soil erosion and reduced moisture conservation. The commercialization of GMHT canola allowed farmers to have efficient weed control from one year to the next, removing the need to summerfallow land to control weeds. The corresponding increase in moisture conservation positively contributed to the increased adoption of nutrient fixing legume crops. The result is that Agriculture and Agri-Food Canada identifies most of Saskatchewan crop land as a low or very low risk of erosion (AAFC 2016).

The results indicate the positive impacts that result from increased fertilizer use efficiency. It is of utmost importance to note that the increased use efficiency that has been demonstrated by the results is based on an overall increased use of fertilizer. As summerfallow has been removed from crop rotations and are now part of continuous crop rotations, more fertilizer will be applied simply due to the change in land management practices. The increased fertilizer use efficiency increases crop yields, highlighting the importance of ensuring that prairie farmers do not face production constraints that would be imposed from reductions in fertilizer use. Numerous governments have established fertilizer reduction mandates, as part of their commitments to mitigating climate change. Our results indicate that such reduction mandates will reduce yield.

The results contribute to quantifying the importance of continual innovation that allows for increasingly productive and sustainable agriculture. Sustainable crop production requires that greater volumes be produced while using consistent land mass. For this to occur, a systems approach to crop production is required. The increased efficiency of crop production systems requires the development of new crop varieties, such as climate adapted pulses and GMHT canola, the increased efficiency of crop inputs, such as fertilizers and chemicals and innovations in farm equipment that facilitate the increased use efficiency. For the system to function efficiently, all of the various components need to be integrated. Enacting a reduction mandate of one of the various aspects has a significant potential to lower the overall efficiency of crop production and sustainability.

6. Conclusion

As pressure to improve the environmental sustainability of agricultural production continues to mount, the results of this research highlight how grain farmers on the Canadian prairies are using fertilizer more efficiently, resulting in lower rates applied per bushel of grain yield. One contributing factor is the expansion of the pulse crop industry. The inclusion of pulses in a crop rotation results in lower fertilizer requirements both for the pulse crop and the crop planted in the subsequent year, as well as a comparative yield increase for cereal crops succeeding pulse crops in a rotation. The adoption of GMHT canola varieties has also contributed to improved fertilizer use efficiency in terms of lbs/bu. Rather than mandating reductions in fertilizer use, fostering increased investment into increased nutrient use efficiency might prove a more effective approach to improving the efficiency of crop input use.

The vast averages presented in this article are derived from different management situations. These practices, ranging from irrigation frequency to pest control measures, play a pivotal role in influencing nutrient applications and yield. The results, while averaged, capture a broad spectrum of these practices, and it is essential to interpret them in the context of this variability. Additionally, the inclusion of pulses within a crop rotation does not have the same frequency across different scenarios and varies widely. It is essential to understand that a rotation with frequent pulse cultivation might have different nutrient dynamics than one with sporadic legume crops.

While the results of the study did not achieve statistical significance, they offer an empirical perspective on the changes in fertilizer use patterns, especially nitrogen, across different crop rotations and periods. The findings, even in the absence of statistical significance, present a comprehensive overview that can inform future research, hypotheses, and methodologies.

Declarations

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Conflicts of interest/Competing interests

The authors have no conflicts of interest or competing interest to declare.

Ethics approval

The survey was granted exemption from ethics approval by the University of Saskatchewan’s Research Ethics Board.

Availability of data and material

The data is protected as per the University of Saskatchewan data protection policies and may be made available upon specific request.

Authors' contributions

EL analyzed the data, in collaboration with CS wrote the background, materials and methods, and results sections, and assisted in reviewing and editing the remaining sections. Additionally, CS assisted in creating and administering the survey, wrote the discussion section, assisted with reviewing and editing the remaining sections. SG assisted in creating and administering the survey, cleaning and analyzing the data. SS assisted in creating the survey, wrote the introduction and conclusion, and contributed to reviewing and editing the remaining sections.

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