Comparative Study on Fertilizer Application Trends in Saskatchewan

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Abstract

Discussions about agricultural practices related to food production and efforts to address climate change are increasing. As these discussions intensify around balancing the need for increased food production with environmental conservation, understanding the dynamics of agricultural practices becomes increasingly important. The challenge becomes one of how to reduce greenhouse gas emissions that align with international commitments while not adversely impacting global food production. This study examines fertilizer application in Saskatchewan and implications for crop yields and efficiency. Utilizing a survey that spans two distinct periods, 1991-94 and 2016-19, we analyzed data from 69 Saskatchewan farms. Our findings underscore that while the total fertilizer applied increased by 145%, fertilizer applications per bushel of crop increased by 50%. Seeded acres increased from 33 million to 40 million acres (22%). This escalation in fertilizer usage was paralleled by a 28% increase in yield, emphasizing the role of optimized fertilizer application in enhancing agricultural productivity. When evaluating nitrogen applications, a 29% increase in nitrogen use efficiency was observed, which is measured in pounds applied per bushel produced. This research emphasizes the importance of not merely assessing fertilizer use in isolation but correlating it with production metrics to obtain a holistic and accurate representation.

Key words: application rate, emission reduction target, land use change, nitrogen, nitrous oxide, yield

Introduction

The escalating global urgency to mitigate climate change has directed international attention towards the agricultural sector [1,2], given its significant contribution to greenhouse gas (GHG) emissions. The Paris Agreement, adopted in December 2015, was a landmark international treaty aimed at limiting global warming to below 2 °C above pre-industrial levels, with an effort to limit the temperature increase to 1.5 °C [3]. While each signatory, including Canada, pledged to adhere to core principles, they retained the autonomy to define their domestic emission reduction targets. Canada, for instance, has committed to a GHG emissions reduction target of 30% by 2030, based on 2005 emission levels [4].

Agriculture, forestry and land use collectively account for 24% of global GHG emissions, with agriculture alone accounting for 18% [5]. Within this context, fertilizer application, especially nitrogen-based ones, emerge as a critical contributor to nitrous oxide (N_2O) emissions. Fertilizer application rates have increased globally, with nitrogen (N) fertilizer application soaring by over 85% between 1980 and 2020. Correspondingly, from 1980-2020, global wheat, barley and pea yields increased by 87%, 52% and 53%, respectively [6]. In the EU, N fertilizer use has decreased by roughly 20% between 1980 and 2020 [7]; however, between 2010-2020, N fertilizer use increased from 9.4 million tonnes (Mt) to 10 Mt [8]. Of the 10 Mt of N applied in 2020, France, Germany, Spain and Poland accounted for a combined 5.5 Mt. Application of phosphorus (P) fertilizer in the EU increased from 1 to 1.2 Mt between 2010-2020 [8]. Agricultural area, including arable lands, pastures and mosaic farmlands, covers 39% of the EU's total land area. 1.4% of agricultural areas were lost in the EU due to conversion into urban areas between 2000 and 2018 [9]. Within the total agricultural area of the EU, the fertilized area comprised 133.9 million hectares. A further 46 million farmable hectares are not fertilized, of which 35.3 million are unfertilized grassland and 10.7 million idle or set-aside land [7]. In the United States (US), total N fertilizer application increased by 14% between 1980 and 2015 [10]. Comparatively, total cropland in the US fell by 11% between 1987-2017[11]. This intensification, reflected in increased yields of crops such as wheat, barley and peas, underscores the economic importance of fertilizers.

In Canada, N fertilizer use approximately doubled between 1980 and 2011, while the use of phosphate and potash remained relatively stable [12]. Correspondingly, recommended N fertilizer rates in the prairies provinces increased by 32-110% for canola crops and 56-97% for wheat crops across the brown, dark brown and black soil zones between 1991 and 2016 [13, 14]. The increase in fertilizer use can be partly attributed to an 88% increase in land treated with commercial fertilizers during this period. In addition, an 89% reduction in Canadian summerfallow acres between 1991 and 2016 contributed to a 13% increase in seeded acres, leading to more land being available for fertilizer application [15]. Canada also saw a 5% decrease in the total acres of farmland during this period, while total farmland in Saskatchewan decreased by 7%. Specifically in Saskatchewan, summerfallow area decreased by 90% between 1991 and 2016, while seeded acres increased by 22%. Agricultural intensification has occurred over the past thirty years as land is no longer left fallow for a full growing season to be tilled as a form of weed control, with this fallow land now in continuous zero or minimum tillage crop production.

The empirical foundation for many fertilizer-related environmental policies worldwide is frequently lacking. For instance, the EU's proposal to reduce fertilizer use by 20% [16], and Canada's aim to curtail nitrous oxide emissions from fertilizers by 30% by 2030, lack solid scientific backing [17]. Such gaps in empirical data for crucial policy decisions raise concerns about the feasibility and implications of these mandates. The absence of such empirical data becomes even more concerning when juxtaposed against the critical need to set realistic targets for GHG emissions and the economic implications of these targets. Precaution is not a robust method for the establishment of emission reduction targets or mandates.

Saskatchewan's agricultural landscape is shaped by its distinctive climate and fertile soils, making it a key region for this investigation. The province's farming practices and trends in fertilizer application offer a microcosm that can yield insights with both local and global implications. As a significant contributor to Canada's agricultural output, understanding Saskatchewan's fertilizer application patterns becomes paramount in the broader discourse on GHG emissions and sustainable agriculture.

The application of N fertilizers plays a contributing factor in the GHG emissions of N_2O. Following fertilizer applications, emissions of N_2O mostly occur through the processes of nitrification, in which ammonia is converted to nitrates, and denitrification, through which nitrates are converted to N_2O or nitrogen gas [18]. Variations in soil emission levels can be attributed to multiple factors. Environmental conditions, and specifically growing season precipitation, are the largest driver of variation in emission levels [19, 20]. A study highlighted by the Global Carbon Project [21, 22] indicates that the use of nitrogen fertilizers in agriculture has been a major factor in the 30% increase in human caused N_2O emissions over the past four decades. Countries with rapidly increasing human caused N_2O emissions include Brazil, China and India. Furthermore, since the 1980s, agricultural N_2O emissions have been escalating the fastest in East and South Asia, South America and Africa. In contrast, North America's agricultural N_2O emissions have remained consistently high, while Europe has witnessed a slight decline in it agricultural N_2O emissions [23].

Research from Manitoba, Canada, indicates that fertilizer application rates play a significant role in determining these emission levels. According to this study by Tenuta et al. [24], application rates explained about 70% of the variability in N_2O emissions when evaluated alone. The authors found that at fertilizer application rates of 100 kg N/ha, the average N_2O emission factor was 4.3% compared to 7.2% at an application rate of 175 kg N/ha. Moreover, the 2022 National Inventory Report points to Canada's considerable N_2O emissions in 2020 at 11.79 Mt carbon dioxide equivalents (CO_2e) [25], with Saskatchewan as a prime contributor. Canada's target of a 30% reduction by 2030 would require a decrease of 3.54 $MtCO_2e$ and a decrease in Saskatchewan of 0.87 $MtCO_2e$. When Canada's current N_2O emissions are broken down by province, Saskatchewan produced 2.9 $MtCO_2e$, Alberta produced 2.35 $MtCO_2e$, Manitoba produced 2.03 $MtCO_2e$ and Ontario and Quebec produced 2.16 and 1.7 $MtCO_2e$, respectively. Comparatively, of 95 million Canadian crop or summerfallow acres in 2021, Saskatchewan, Alberta and Manitoba made up 43%, 27%, and 12%, respectively. Ontario and Quebec combined made up only 14%. Unlike absolute emission calculations, emission intensity calculations take into consideration emissions divided by unit production or area of production. Among global competitors, Canada is positioned as a leader in terms of lowering emission intensity. Per hectare of cropland, total direct and indirect fertilizer emissions in Canada are 0.4 tonnes of CO_2e compared to 0.8 tonnes of CO_2e in the US. Total emissions per tonne of N fertilizer in Canada are as high as 4.5 tonnes of CO_2e compared to 7.1 tonnes of CO_2e in the US [25].

Understanding these fertilizer application nuances in Saskatchewan's context is essential. While the direct measurements of GHG emissions vis-à-vis fertilizer applications remain beyond this study's scope, in addition to addressing the empirical gap for policy makers, the study uses primary farm fertilizer data to set the stage for more extensive, targeted research on GHG emissions resulting from fertilizer applications.

To gather this data, an extensive crop rotation survey was developed at the University of Saskatchewan, which collected data pertaining to on farm fertilizer use over the periods of 1991-1994 and 2016-2019. Data collected included nutrient mixture, application rates, total acres of application, seeded acres and crop type. The results allow for a robust comparison of fertilizer use, applications and yields between the two periods, as well as the ability to quantify changes between the two periods.

2. Materials and Methods

To comprehensively assess the changes and implications of fertilizer application rates in Saskatchewan over the specified periods, we employed a structured, data-driven approach. Our primary research tool was an extensive crop rotation survey distributed online to Saskatchewan farmers 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. Utilizing an online survey as the data-collection method facilitated the participation of demographically different participants across Saskatchewan, ensuring a representative sample. This method allowed for the collection of data despite the restrictions that had been put in place during the COVID-19 pandemic, as well as allowing participants to work on the survey while having access to their farm records. The survey was granted exemption from ethics approval by the University of Saskatchewan's Research Ethics Board. By completing the panel of surveys, which typically took between 3-5 hours, participants were entitled to receive up to $200 in compensation.

Participants 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. The data used for this analysis focuses on the amounts and concentrations of fertilizer used by producers throughout their rotations, which included the production of cereals, pulses, oilseeds or the field being left to summerfallow.

This analysis examines changes in fertilizer applications during seeding preparation, seeding, in-crop and post-harvest. Participants were asked to report the type of crop they planted, yield for each crop year and the number of fertilizer applications made, if any. For each year of their crop rotation and each fertilizer application pass, participants were asked about N (nitrogen), P (phosphorus), K (potassium) and S (sulphur) percentages by weight applied, followed by the rate in pounds per acre (lbs/acre) at which they applied total fertilizer and cost of fertilizer application. Responses to these questions were used to derive the average amounts of NPKS per acre each year for both periods. Respondents were asked these questions for all application passes for pre-seed, seeding, in-crop and post-harvest. However, only responses on the first application pass are counted toward the derived values because responses on the second and third pass were very limited (e.g., one response on N percentage for pre-seed in 1991) or not provided at all.

While the dataset used for this study does not encompass direct measures of GHG emissions, we discussed the well-established relationship between nitrogen fertilizer application rates on GHG emission levels in the introduction of this article, using peer-reviewed literature. This provided context and highlighted the potential environmental implications of the observed trends in fertilizer use without making it the focus of our study.

Originally, the Saskatchewan farmer dataset included 160 participants, but for the purposes of this analysis, a subset consisting of 69 respondents is used. This includes farmers that have continuously farmed the land, whether it is one family or a family farm, resulting in the subset consisting of only respondents that have farmed in both crop rotation periods. Additionally, direct comparison of the estimates can be done. Data cleaning and analysis were performed using Excel and R software. Data cleaning process for both periods involved removing duplicate data, outliers, respondents that did not farm either in the 1991-94 or 2016-19, those with incomplete responses in terms of crop yield, crop types planted during each full crop rotation, as well as duplicate data. Outliers were identified as observations with extremely high values of seedable acres and fertilizer rates. 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 applied. 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.

The 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.

Most participants fall in the age category of over 55 (53%) compared to younger farmers (42%). It must be noted that the age represents the age of respondent, however there might be the case that they are reporting data from a family farm that has data extending back to the early 1990s. This explains why the sample contains a small percentage of respondents under the age of 35 during the 1990s crop rotation period. In terms of education, 71% of farmers reported receiving post-secondary education compared to 19% who reported a high school diploma as the highest level of education achieved. When asked if farmers collected off-farm income, 23% of participants responded ‘yes’. Approximately 5% of respondents did not submit an answer regarding age, education and off-farm income. In addition, a small percentage of respondents were farming a total land base under 760 acres (10%). The majority of participants reported a farm size between 1,120 acres and 1,599 acres. Table 1 provides the survey sample demographics.

Table 1: Participant demographics compared to 2016 Saskatchewan Census of Agriculture data

Fertilizer Survey		**Saskatchewan 2016 Census of Agriculture Data**	
Age		**Age**	
Under 35	10%	Under 35	10%
35 to 54	32%	35 to 54	34%
55 and over	53%	55 and over	56%
Education		**Education**	
Post secondary education	71%	Post secondary education	48%
High school diploma	19%	High school diploma	35%
No high school diploma	4%	No high school diploma	17%
Prefer not to say	1%	Prefer not to say	-
Collect off-farm income		**Collect off-farm income**	
Yes	23%	Yes	42%

No	72%	No	58%
Farm Size		**Farm Size**	
Under 399 acres	4%	Under 399 acres	30%
400-760 acres	6%	400-760 acres	15%
760-1,119 acres	16%	760-1,119 acres	10%
1,120-1,599 acres	38%	1,120-1,599 acres	10%
1,600-2,239 acres	14%	1,600-2,239 acres	10%
2,240-2,879 acres	7%	2,240-2,879 acres	7%
2,880-3,519 acres	3%	2,880-3,519 acres	5%
3,520 acres or more	12%	3,520 acres or more	13%

Note: 2016 census data is used for comparison rather than 2021 data, as it aligns with the 2016-19 survey period.

3. Results and Discussion

Our research primarily examines changes in fertilizer application practices in Saskatchewan between two distinct periods: 1991-94 and 2016-19. The results, both in terms of raw data and interpretations, provide insights into broader agricultural practices, revealing the province's evolving agronomic strategies over the decades.

Between the periods of 1991-94 and 2016-19, we observed a 102% increase in the average annual total fertilizer application. Concurrently, average crop yields amplified by 28%. A regression analysis revealed a significant positive relationship between the increase in fertilizer application and the rise in crop yields with a regression of $\beta = 0.87$, $p < 0.05$. This suggests that for every 1% increase in fertilizer application, there is a corresponding 0.87% increase in crop yields. To further validate this relationship, Pearson's correlation was calculated and yielded a coefficient of $(r) = 0.92$, $p < 0.05$, signifying a strong positive association between increased fertilizer applications and crop yields. The correlation between increased fertilizer applications and yields resulted in a 50% surge, measured in terms of pounds of fertilizer applied per bushel of crop produced. Pearson's correlation coefficient solidified further the strong association between these variables, as detailed in Table 2.

Table 2: Change in average annual Saskatchewan fertilizer use: 1991-94 to 2016-19

Period	Crop yield (bu/ac)	Fertilizer applied (lbs/ac)	Fertilizer rate (lbs/bu)	Crop acres (millions)
1991-94	40	231	6	33.3
2016-19	51	467	9	40.5
Percent increase	28%	102%	50%	22%

Scaling the survey fertilizer usage data to match the provincial crop production acres of 33.3 million acres in 1991-94 and 40.5 million acres in 2016-19 [15], we estimated that the total fertilizer usage escalated from 7.7 billion lbs in the period of 1991-94 to 18.9 billion lbs in 2016-19. This translated to a net use surge of 145%. This significant increase might be influenced by several factors. Further multivariate analysis could help pinpoint the primary drivers of this increase, considering variables such as changes in crop types, market demand and technological advancements. Speaking of which, the adoption of modern equipment and technological advancements have facilitated better assessment of nutrient needs, leading to a shift in both average annual application rates and their timing over these 30 years.

From 1991-94 to 2016-19, Saskatchewan farmers converted 7.2 million acres of summerfallow to continuous crop production, thereby increasing the overall fertilizer use, as summerfallow production does not require the use of fertilizers. Survey data from 1991-94 confirms that no fertilizer applications were made on surveyed summerfallow fields. The conversion alone accounts for 44% of the increase in fertilizer usage. Similarly, between these two time periods, total crop production rose from 1.3 billion bu to 2.1 billion bu, an increase of 62%. To understand the implications of this shift, we applied a regression model using a dummy variable approach more deeply. By designating the 1991-94 period as ‘0’ and the 2016-19 period as ‘1’, the model captures the average fertilizer usage for each period, and the coefficient of the dummy variable indicates the change between them. The model suggests a substantial shift in fertilizer usage between two periods. However, caution is warranted. While the change in fertilizer use is apparent, the regression does not confirm that this shift is solely due to the elimination of summerfallow fields; other confounding factors could influence this change.

Total fertilizer applications can be broken down by the rate applied per bushel of crop yield. This analysis found that fertilizer per bushel in Saskatchewan increased by almost 31% between the studied periods. The changes in specific elemental components of fertilizer blends can be further analyzed in terms of pounds applied per bushel of grain. Results found an increase in all four fertilizer components on a per bushel basis, as presented in Table 3. The results show that the nutrient uptake per bushel has not changed drastically between the two periods.

The values of N, P and S uptake reported by Saskatchewan farmers as part of this study are comparable in magnitude to what the Government of Saskatchewan has published [26]. Fact sheets on N fertilization in crop production for Saskatchewan published by the provincial government indicate that the nitrogen uptake by crops varies, on a pound per bushel basis, ranging from 1.2 – 1.5 lbs/bu for winter wheat and 2.9 – 3.5 lbs/bu for canola. Regarding P uptake, the magnitude varies from 0.67 – 0.82 lbs/bu for barley to 1.31-1.63 lbs/bu for canola. In terms of S uptake, values from 0.16 lbs/bu for barley to 0.54 lbs/bu for canola are reported [27].

Table 3: Changes in elemental fertilizer components (lbs/bu)

Period	N	P	K	S	Total fertilizer
1991-94	4.1	1.4	0.7	0.8	7
2016-19	5.3	1.8	0.8	1.3	9.2
Percent change	29%	29%	14%	63%	31%

Our analysis also highlighted a paradigm shift in the timing of fertilizer applications. Data from 1991-94 showcased no in-crop applications, presumably due to equipment constraints. By 2016-19, we found that 13% of the total N fertilizer was applied in-crop, with the remaining N applied pre-seed (29%), with the seed (27%) and post-harvest (31%). This shift is detailed in Table 4.

To validate these observed differences, we employed an ANOVA test using the application timings as variables. The ANOVA results indicated a significant F-value (42.7) (with a p-value of 0.03), underscoring that the differences in application timings between the two periods were statistically significant at the 95% significance level. This result statistically underscores the evolving fertilizer application strategies over the studied decades in Saskatchewan.

Table 4: Changes in fertilizer application timing (lbs/acre/year)

		1991-94	2016-19	Percent Change
Average pre-seed	N	56	82*	46%
	P	28	35*	25%
	K	12	0*	↓
	S	16	26*	63%
Average with seed	N	30	77	157%
	P	24	39	63%
	K	22	29	32%
	S	14	21	50%
Average in-crop	N	0.0*	36	↑
	P	0.0*	17	↑
	K	0.0*	9	↑
	S	0.0*	17	↑
Average post-harvest	N	70	90	11%
	P	0	17	↑
	K	0	9	↑
	S	0	15	↑
Total average of fertilizer application in a year from pre-seed to post-harvest	N	156	285	83%
	P	52	108	108%
	K	34	47	38%

	S	30	79	163%

** No pre-seed fertilizer applications were reported in 2019.*

*** 1991-94 indicated no in-crop fertilizer applications; therefore, percent change is indicated by the direction of growth and not a value.*

During the crop rotation of 1991-94, only 12% of farmers conducted soil testing, half of whom saw an increase in soil fertility. Soil testing is considered critical to determining the appropriate rate of nitrogen fertilizer to apply to match crop yield potential [27].

Survey data shows that the total volume of fertilizer used in Saskatchewan has increased by 145% and the amount of fertilizer used for each bushel of yield has increased by 50% between 1991-94 and 2016-19, while crop acres increased by 22% (Table 2). An independent t-test revealed significant differences in fertilizer application rates between these two periods ($t=8.4$, $p<0.005$). This contrast in the growth rates suggests that while there was a substantial rise in overall fertilizer use, its application relative to crop yield became more efficient, potentially due to changes in soil quality, shifts in crop varieties or advancements in farming techniques over the years. Furthermore, when fertilizer use is allocated into the specific elemental components, N use per bushel (lbs/bu) has increased by 29%, similar to the level of increase seen in average crop yields (28%) (Table 3).

Fact sheets on nitrogen fertilization in crop production for Saskatchewan indicate that the nitrogen uptake by crops varies from 61 – 74 lbs/acre to 138 – 168 lbs/acre. On a pound per bushel basis, the estimates fall within the ranges of 1.2 – 1.5 lbs/bu for winter wheat and 2.9 – 3.5 lbs/bu for canola [27]. Although the magnitudes of the estimates are comparable in some of the cases, it must be noted that there is a fundamental difference in the source of the data. The source of the data used in the provincial fact sheet is from the Canadian Fertilizer Institute and Nutrient Uptake and Removal by Field Crops Guideline for Western Canada. However, the information provided by this tool on crop nutrient uptake and removal may not reflect current crop yields and requires revision [28].

In a comparative analysis with global standards, Saskatchewan's trend of augmented fertilizer use is evident. Notable the province increased a 62% surge in crop production. If we maintain the assumption that the province's crop acreage remained unchanged between the two periods, there would still be a notable 28% increment in total production. This trajectory of nitrogen fertilizer application and crop production over long periods of time is consistent with the estimates provided in literature [29].

Our data highlights a significant increase in fertilizer usage in Saskatchewan, which is mirrored by an enhanced crop yield. Specifically, although our dataset does not provide direct evidence of reduced N_2O emissions per bushel of grain, it does indicate that Saskatchewan farmers have managed to considerably increase crop yields. This is a critical point, given the rising global food and commodity demands.

A notable highlight of our study is the contribution of 22% growth in cultivated land in Saskatchewan, largely due to the reduction in summerfallow areas, to a 44% rise in fertilizer consumption. As summerfallow areas were reduced, there was a consequential increase in both fertilizers use and potential N_2O emissions. However, it is important to note that the decrease in summerfallow areas has been associated with heightened carbon sequestration, leading to reduced CO_2 emissions from the soil and improved soil quality, as supported by Sutherland et al. [30]. Additionally, as fertilizer use goes up and contributes to better yields, more plant biomass becomes available, which can further sequester carbon [31, 32]. However, it is also essential to consider that as the soil's organic matter breaks down over time, emissions of both CO_2 and N_2O can increase.

Saskatchewan's contribution to Canada's total cropland stands at around 43%, but interestingly, it accounts for only 25% of the nation's agricultural N_2O emissions. In contrast, Ontario and Quebec, which contribute significantly less to national cropland (10% and 5% respectively), emit a combined 33% of national N_2O emissions [25,15]. The data indicates that crops on the prairies are being produced more efficiently, in terms of pounds of fertilizer applied, than in eastern Canada. One possible contributing factor to this variation in fertilizer efficiency could be the difference in crops produced. For example, corn is more commonly grown in eastern Canada than on the prairies and requires higher levels of N fertilizer than other crops [33]. The relatively drier climate on the prairies can also contribute to lower soil emission levels [34].

This discrepancy in the relationship between the proportion of cropland and the corresponding N_2O emissions across different regions in Canada implies that a one-size-fits-all approach to emission reduction might not be the most effective. Implementing a flat 30% reduction across all provinces could disproportionately impact regions like Saskatchewan that already have a lower emission intensity.

Additionally, achieving the Canadian federal government's goal of reducing fertilizer emissions by 30% below 2020 levels will require changes in fertilizer management practices. If the focus of fertilizer reductions is indicated as a 30% overall reduction, meeting a mandate of this nature would be impossible under current circumstances and agronomic tools, as increases in cultivated land would constantly result in greater fertilizer applications. However, if fertilizer use or N_2O emissions are analyzed by the intensity of their use, achieving a 30% reduction may become economically feasible. It is noted that farmers have also split fertilizer applications throughout the year, including in-crop applications, which was not practiced in the early 1990s. The practice of splitting fertilizer applications throughout the year is a recommended practice by the Government of Canada to increase fertilizer use efficiency [17].

The recent surge in fertilizer prices since 2020, influenced by factors like the Covid-19 pandemic and geopolitical tensions [35], means farmers are less inclined to use more fertilizer than absolutely necessary. With 67% of Canadian farmers in 2019 being aware of 4R fertilizer management principles, it is likely that more farmers are adopting these strategies to ensure efficient use [36]. Pushing for drastic reductions in fertilizer use might have unintended consequences on production, especially if these reductions exceed what is minimally needed to achieve target yields.

4. Conclusions

In the evolving landscape of agricultural policymaking, the necessity for accurate, empirical data cannot be overstated. Decisions made without a solid foundation in current, on-the-ground realities risk not only inefficiency but also unintended economic consequences.

Our study offers and indispensable lens into the changing agricultural practices in Saskatchewan. We highlighted a 29% increase in the use of N fertilizer per bushel of crop produced. This increment, set against the backdrop of broader crop production trends like the decline of summerfallow, paints a vivid picture of a province dynamically adapting its farming techniques. Notably, these shifts have been powered by advancements in equipment and technology, occurring organically without external policy interventions.

While numerous studies provide insights into agricultural trends, our research stands out for its granularity and specificity to Saskatchewan's unique context. It underscores the importance of region-specific data, which is paramount for crafting informed, effective, and tailored policies.

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

References

[1]. Paris Agreement. (2015). United Nations Treaty Collection. Available online: https://treaties.un.org/doc/Publication/MTDSG/Volume%20II/Chapter%20XXVII/XXVII-7-d.en.pdf (accessed on March 30, 2023).

[2]. Schmidt, J. (2015). Paris Climate Agreement Explained: What actions did countries commit to implement? Natural Resources Defense Council. Available online: https://www.nrdc.org/bio/jake-schmidt/paris-climate-agreement-explained-what-actions-did-countries-commit-implement (accessed on March 30, 2023).

[3]. The Paris Agreement | UNFCCC. (2015). United Nations Climate Change. Available online: https://unfccc.int/process-and-meetings/the-paris-agreement (accessed on March 30, 2023).

[4]. Government of Canada. Canada's Climate Change Actions and Targets. Available online: https://unfccc.int/sites/default/files/resource/2_Canada.pdf (accessed on April 2, 2023).

[5]. International Panel on Climate Change. 2014. Assessment Report 5 Climate Change 2014: Mitigation of Climate Change. Available online: https://www.ipcc.ch/report/ar5/wg3/ (accessed on April 1, 2023).

[6]. FAO. 2022. Crops and livestock products. FAOSTAT. Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on April 2, 2023).

[7]. Forecast of food, farming and fertilizer use in the European Union 2021-2031. Available online: https://www.fertilizerseurope.com/wp-content/uploads/2021/12/Forecast-2021-31-Studio-final-web.pdf (accessed on October 3, 2023).

[8]. Eurostat. 2022. Agri-environmental indicator – mineral fertiliser consumption. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption#Analysis_at_country_level (accessed on October 20, 2023).

[9]. Agriculture and food system. (n.d.). European Environment Agency. Available online: https://www.eea.europa.eu/en/topics/in-depth/agriculture-and-food?activeTab=fa515f0c-9ab0-493c-b4cd-58a32dfaae0a&activeAccordion=4268d9b2-6e3b-409b-8b2a-b624c120090d (accessed on October 20, 2023).

[10]. United States Department of Agriculture. 2019. All fertilizer use and price tables in a single workbook. Economic Research Service. Available online: https://www.ers.usda.gov/data-products/fertilizer-use-and-price/ (accessed on September 20, 2023).

[11]. United States Department of Agriculture. 2017 Census of Agriculture - United States Summary and State Data. Volume 1. Geographic Area Series. Part 51. AC-17-A-51. Available online: https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf (accessed on September 20, 2023).

[12]. Dorff, E., and Beaulieu, M. S. Canadian Agriculture at a Glance: Feeding the soil puts food on your plate. Statistics Canada Agriculture Division. Statistics Canada, 2014; Catalogue no. 96-325-X-No.004. ISSN 0-662-35659-4. Available online: https://www150.statcan.gc.ca/n1/en/pub/96-325-x/2014001/article/13006-eng.pdf?st=BMVP55YE (accessed on May 3, 2023).

[13]. Saskatchewan Agriculture and Food and Saskatchewan Rural Development. Crop Planning Guide 1991. Available online: https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients

[14]. Government of Saskatchewan. Crop Planning Guide 2016. Available online: https://publications.saskatchewan.ca/#/products/77820 (accessed on May 3, 2023).
[15]. Statistics Canada. Table 32-10-0153-01 Land use, Census of Agriculture historical data. Available online: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210015301 (accessed on May 3, 2023).
[16]. European Commission. A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:ea0f9f73-9ab2-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF (accessed on October 20, 2023).
[17]. Government of Canada. Achieving a Sustainable Future. Draft Federal Sustainable Development Strategy 2022 to 2026. Cat No.: En4-136/2022E-1-PDF. Available online: https://www.fsds-sfdd.ca/downloads/2022-2026_DRAFT_FSDS.pdf (accessed on May 5, 2023).
[18]. Bernhard, A. 2010. The Nitrogen Cycle: Processes, Players, and Human Impact. Nature Education Knowledge 3(10): 25. Available online: https://www.nature.com/scitable/knowledge/library/the-nitrogen-cycle-processes-players-and-human-15644632/ (accessed on May 3, 2023).
[19]. Giweta, M., Dyck, M. F., Malhi, S. S. Growing season nitrous oxide emissions from a Gray Luvisol as function of long-term fertilization history and crop rotation. Can. J. Soil Sci. 2017, 97, 474-486, https://doi.org/10.1139/cjss-2016-0106.
[20]. Rochette, P., Liang, C., Pelster, D., Bergeron, O., Lemke, R., Kroebel, R., MacDonald, D., Yan, W., Flemming, C. Soil nitrous oxide emissions from agricultural soils in Canada: Exploring relationships with soil, crop and climatic variables. Agric. Ecosyst. Environ. 2018, 254, 69-81, https://doi.org /10.1016/j.agee.2017.10.021.
[21]. Dunne, D. (2020). Nitrogen fertiliser use could 'threaten global climate goals.' Carbon Brief. Available online: https://www.carbonbrief.org/nitrogen-fertiliser-use-could-threaten-global-climate-goals/ (accessed on May 22, 2023).
[22]. Tian, H., Xu, R., Canadell, J. G., Thompson, R. L., Winiwarter, W., Suntharalingam, P., Davidson, E. A., Ciais, P., Jackson, R. B., Janssens-Maenhout, G., Prather, M. J., Regnier, P., Pan, N., Pan, S., Peters, G. P., Shi, H., Tubiello, F. N., Zaehle, S., Zhou, F., … Yao, Y. A comprehensive quantification of global nitrous oxide sources and sinks. Nature 2020, 586, 248–256, https://doi.org /10.1038/s41586-020-2780-0.
[23]. Thompson, R. L., Lassaletta, L., Patra, P. K., Wilson, C., Wells, K. C., Gressent, A., Koffi, E. N., Chipperfield, M. P., Winiwarter, W., Davidson, E. A., Tian, H., & Canadell, J. Acceleration of global N2O emissions seen from two decades of atmospheric inversion. Nat. Clim. Chang., 2019, 9, 993–998, https://doi.org/10.1038/s41558-019-0613-7.
[24]. Tenuta, M., Amiro, B. D., Gao, X., Wagner-Riddle, C., Gervais, M. Agricultural management practices and environmental drivers of nitrous oxide emissions over a decade for an annual and an annual-perennial crop rotation. Agric. For. Meteorol. 2019, 276-277, https://doi.org /10.1016/j.agrformet.2019.107636.
[25]. Fertilizer Canada. Fertilizer Canada Consultation Response: Reducing emissions arising from the application of fertilizer in Canada's agriculture sector. Available online: https://fertilizercanada.ca/wp-content/uploads/2022/09/Fertilizer-Canada_ERI-Consultation-Response.pdf (accessed on April 15, 2023).
[26]. Government of Saskatchewan. Nitrogen Fertilization in Crop Production. Fact sheet. Available online: https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/nitrogen-fertilization-in-crop-production (accessed on April 15, 2023).
[27]. Government of Saskatchewan. Soils, Fertility and Nutrients. Available online: https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients (accessed on March 15, 2023).

[28]. SaskWheat. Revising the crop nutrient uptake and removal guidelines for Western Canada. Available online: https://saskwheat.ca/research-project-articles/revising-the-crop-nutrient-uptake-and-removal-guidelines-for-western-canada (accessed on March 15, 2023).
[29]. Awada, L., and Phillips, P. W. Challenges and Potential Solutions to Improve Fertilizer Use Efficiency and Reduce Agricultural GHG Emissions. Policy Brief, Plant Phenotyping and Imaging Research Centre, 2021. Available online: https://p2irc.usask.ca/articles/2021/challenges-and-potential-solutions-to-improve-fertilizer-use---may-2021-final.pdf (accessed on March 20, 2023).
[30]. Sutherland, C.; Gleim, S.; Smyth, S.J. Correlating Genetically Modified Crops, Glyphosate Use and Increased Carbon Sequestration. Sustainability 2021, 13, 11679. https://doi.org/10.3390/su132111679.
[31]. Han, S., Li, X., Luo, X., Wen, S., Chen, W. and Huang, Q. Nitrite-oxidizing bacteria community composition and diversity are influenced by fertilizer regimes, but are independent of the soil aggregate in acidic subtropical red soil. Front. Microbiol. 2018, 9,885. https://doi.org/10.3389/fmicb.2018.00885.
[32]. Hijbeek R, van Loon MP, van Ittersum MK. 2019. Fertiliser use and soil carbon sequestration: opportunities and trade-offs. CCAFS Working Paper no. 264. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online: www.ccafs.cgiar.org
[33]. Abalos, D., Jeffery, S., Drury, C. F., Wagner-Riddle, C. Improving fertilizer management in the U.S. and Canada for N2O mitigation: Understanding potential positive and negative side-effects on corn yields. Agric. Ecosyst. Environ. 2016, 221, 214-221. https://doi.org/10.1016/j.agee.2016.01.044
[34]. Agriculture and Agri-Food Canada. Greenhouse gases and agriculture. Available online: https://agriculture.canada.ca/en/agriculture-and-environment/climate-change-and-air-quality/greenhouse-gases-and-agriculture (accessed on May 20, 2023).
[35]. Schnitkey, G., N. Paulson, C. Zulauf, K. Swanson, J. Colussi and J. Baltz. "Nitrogen Fertilizer Prices and Supply in Light of the Ukraine-Russia Conflict." farmdoc daily (12):45, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, April 5, 2022. https://farmdocdaily.illinois.edu/2022/04/nitrogen-fertilizer-prices-and-supply-in-light-of-the-ukraine-russia-conflict.html
[36]. Fertilizer Canada. Fertilizer Use in Canada. 4R Nutrient Stewardship Grower Adoption. Available on: https://fertilizercanada.ca/our-focus/stewardship/fertilizer-use-survey/#:~:text=Fertilizer%20Canada%20promotes%20the%20voluntary%20adoption%20of%204R,ability%20to%20report%20on%20sustainable%20nutrient%20stewardship%20practices (accessed on May 20, 2023).