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Impacts of reduced tillage on soil health in Saskatchewan

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ABSTRACT

On the Canadian Prairies, decades of high-disturbance land management practices, including summerfallow and conventional tillage, contributed to soil erosion and declines in soil quality indicators, including soil organic matter (SOM). However, shifts to zero tillage, minimum tillage and continuous cropping following the adoption of genetically modified crops, instead of summerfallow have helped restore lost organic matter. To assess changes in SOM as summerfallow practices and tillage have been reduced and removed from land management practices, an online survey of Saskatchewan farmers was conducted between October 2024 and March 2025, with farmers voluntarily reporting summerfallow and tillage practices along with SOM level data. Results show that, between 1990-2024, the average number of annual tillage passes decreased 76% and the average percentage of summerfallow fields decreased 91%. Correspondingly, average reported SOM levels increased 41% between the periods of 1990-1999 and 2015-2024. Shifts towards sustainable management practices were made possible by adoptions of innovative technologies, including both genetically modified and conventionally-bred herbicide tolerant cropping systems and more efficient herbicides. The relationship between increasing SOM levels and the shift towards low-disturbance farming systems shows how innovative changes in farmers' land management practices are helping to regain SOM previously lost to intense cultivation across the province.

1. Introduction

Improvements in soil health are a key part of increasing the sustainability of agriculture. Many of today's farmers began when the use of mechanical tillage and summerfallow was the leading form of weed control, which led to wind and water erosion of soils, nutrient losses, and watershed runoff concerns. Innovations in equipment, crop genetics, fertilizers, and pesticides have all contributed to the shift away from the weed management practices of summerfallow and intensive tillage. However, quantifying soil health improvements is not a simple process, as soil is a complex system (Lehmann et al., 2020). Indicators for soil health in the literature include wet aggregate stability, soil pH, electronic conductivity, cation-exchange capacity, bioavailable nutrients, soil active carbon dioxide (CO_2), soil protein, pore-size diversity, water storage, aggregation, and nitrous oxide (N_2O) production, among others (Lehmann et al., 2020; Wu et al., 2024).

One important contributor to productivity is soil organic matter (SOM), as it improves both physical and chemical properties of the soil (Mehra et al., 2018). Benefits of SOM include improved soil fertility, water movement, soil structure stability, and erosion resistance (Mehra et al., 2018; Victoria et al., 2012). Improvements in soil properties, such as water-holding capacity and improved microbial activity, contribute to improvements in crop yield. The yield response is dependent on crop type and is typically higher in sandier soils, or in either very wet or very dry climates, and is dependent on crop type (Hijbeek et al., 2026). However, the extent of the direct cause-effect relationship between SOM and crop yields is still uncertain (Lal, 2020; Manns and Martin, 2018; Schjønning et al., 2018).

There are several required conditions for a parameter to be useful as a soil health indicator. The indicator must be: 1) relevant; 2) sensitive; 3) practical; and 4) informative (Lehmann et al., 2020; Rinot et al., 2019). Soil organic matter levels meet conditions 1, 3, and 4 fully, and while SOM does not typically change quickly in response to management changes, it has been shown to reflect changes over time, making changes in SOM a useful representation of overall soil quality levels. Evidence of SOM levels being significantly influenced by soil and crop management practices, such as tillage, summerfallow, use of cover crops, agriculture forest systems, and organic farming, is cited in previous literature (Lehmann et al., 2020; Chen et al., 2020; Jian et al., 2020; McArthur et al., 2001; Schnitzer et al., 2006). On the Canadian Prairies, tillage peaked in the 1970s and then drastically decreased to minimal levels by the 2020s. This shift in management practices coincide with the

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introduction of genetically modified herbicide tolerant (GMHT) canola in 1997. GMHT canola was approved in 1995 and entered a two-year multiplication program, with 30,000 acres in 1995 and 230,000 acres in 1996 (Smyth and Phillips, 2001). The efficient weed control achieved by farmers allowed them to consistently remove tillage as their leading form of weed control, transitioning land into continuous crop, zero or minimum tillage practices. Reduced tillage helps to increase soil particulate aggregation and decrease the rate of decomposition, reducing the release of SOM from agricultural soils (Mehra et al., 2018; Six et al., 1999). The increase in crop residue levels returning to the soil with the removal of summerfallow also contributes to improved SOM levels (Machado et al., 2015).

The objective of this article is to analyze changes in SOM levels reported from farm-level soil sample results across Saskatchewan, based on the hypothesis that SOM levels increased following the transition away from tillage-based land management systems to continuous cropping-based systems, as well as increased rates of fertilizer application. While supporting literature exists on the use of reduced tillage and summerfallow practices to improve soil health, this analysis is novel in that it uses farmer-reported management and soil sample data spanning over 30 years in the province of Saskatchewan.

2. Methodology

Data for this study were collected from farmers in Saskatchewan, Canada, through an online Crop Rotation Survey. Hosted by the University of Saskatchewan, the survey collected farm-level management data from Prairie crop farmers on all operations from seeding to harvest, including fertilizer, tillage, and chemical applications. The survey was first introduced in 2020, collecting data from the 1991-1994 and 2016-2019 crop production years between November 2020 and March 2021. In 2024, the survey was relaunched from October 2024 to March 2025, collecting data from the 2004-2006 and 2020-2024 crop production years.

The survey collected detailed crop production data such as rotation, varieties planted, soil sampling results, fertilizer and chemical input rate, crop yields, and the number of equipment passes across a field, as well as demographic information. In both sets of surveys, farmers were asked to choose one field on which to report their practices on, and if possible, use the same field for both periods under study, allowing for direct comparison of their management practices between the periods. The survey was divided into four sections, seeding, fertilizer, tillage, and chemical applications.

Participants were recruited through social media, email, and through communication channels of public and industry partners, including the provincial crop commission groups and agricultural colleges and departments across the Prairies. Participants were compensated $50 for each completed section, totaling $200 for completion of all four components. Before launching the survey in 2020, the University of Saskatchewan's Research Ethics Board granted the survey an official exemption from ethics approval due to both the objective nature of the survey and the absence of direct focus on human subjects.

The survey was available to farmers across the Prairie Provinces of Alberta, Saskatchewan, and Manitoba; however, most farmers who completed the survey were from the province of Saskatchewan. Due to low response rates from the other two Prairie Provinces, the analysis was limited to Saskatchewan farmers for all periods. While ideally participants were able to complete the survey for all crop production periods, many participants were not actively farming for the full 34 years and so only filled out the questions for the years applicable to them. This resulted in different sample sizes for each of the crop production periods under study. A total of 137 Saskatchewan farmers completed the first set of surveys in 2020-2021, and after removing incomplete and duplicate responses, the final sample size for the analysis of the 2020-2021 survey was 124, with 63 participants completing the questions for the 1991-1994 period and 123 completing the questions for the 2016-2019 period. The 2024-2025 version of the survey was completed by 81 participants; however, after removing incomplete and duplicate responses as well as the responses from Alberta and Manitoba, the final sample size for Saskatchewan was 63. Forty-seven of these 63 total participants fully completed the questions needed for the 2004-2006 period and 57 completed the questions for 2020-2024.

The participants from both surveys were distributed roughly evenly across the provincial regions and soil zones. Fig. 1 shows the rural municipalities (RM) within which the fields reported on by participants in both the first and second rounds of the Crop Rotation Surveys were located. As illustrated on the provincial maps, all agricultural regions of the province are represented by participants. Because climate and soil characteristics are important factors when making soil and residue management decisions, the data in the present analysis is broken into three main soil zone regions based on the online Saskatchewan Soil Information System's provincial soil zone map: brown, dark brown, and combined black and grey soil zones (SKIS Working Group 2025). For the remainder of the article, the combined black and grey soil zones is referred to as the black soil zone for simplicity.

Compared to the 2021 Census of Agriculture sample, the sample of Saskatchewan farmers who completed the survey in both periods farmed slightly more acres, achieved higher levels of education, spent less time at off-farm employment, and were younger than the average farmer (Table 1). These differences might partly be attributed to younger farmers being more comfortable filling out surveys online. Farmers who are also not employed off-farm might have had more time in the winter months to complete the survey. Additionally, the higher number of participants who received post-secondary education might partly be explained by University of Saskatchewan alumni who stay interested in research coming from the university they attended. However, despite the minor demographic differences between the survey samples and the Census of Agriculture data, the sample is representative of Saskatchewan crop farmers and therefore allows a robust analysis.

One challenge with using survey data for analytical purposes is that the quality of the data is only as high as the quality of the survey responses without viewing participant records or making in-person site visits. It is especially challenging to ensure high-quality data when asking survey participants to recall management decisions from years past, creating the opportunity for recall bias due to having incomplete information about the practices used. Fortunately, many farmers keep some form of detailed records. Participants were asked if they accessed historical records to help when completing the survey and 74% - 90% of respondents, depending on the survey period, reported that they did access their farm records. Despite the use of records to respond to questions, data from historical periods is limited to the information that respondents were able to provide. To examine the relationship between soil disturbances and soil health levels, detailed historical tillage data, summerfallow data, crop yield data, as well as historical soil sample results were needed. For the tillage section of the survey, participants were asked to provide the number of passes, implements used, and depth of each tillage pass made in each of the years under study. They were also asked to document the number of times they harrowed or harrow-packed the field, as these residue management strategies disturb the soil, although to a lesser extent than conventional tillage passes for weed control. For the present analysis, a traditional tillage application made either pre-seed or post-harvest was assigned a value of 1 pass per year, while a harrow or harrow-pack operation was assigned a value of 0.5 passes per year to account for the lower level of soil disturbance caused by these practices. For each participant, the corresponding values of their tillage and harrow passes each year were quantified under this assumption, allowing for an examination of the change in the number of times the soil was disturbed across Saskatchewan between 1991-2024. Participants also reported their crop rotation and summerfallow practices for each of the studied periods. The percentage of fields left to summerfallow within each year of the study period was averaged across the Saskatchewan soil zones to document the changes in use of this

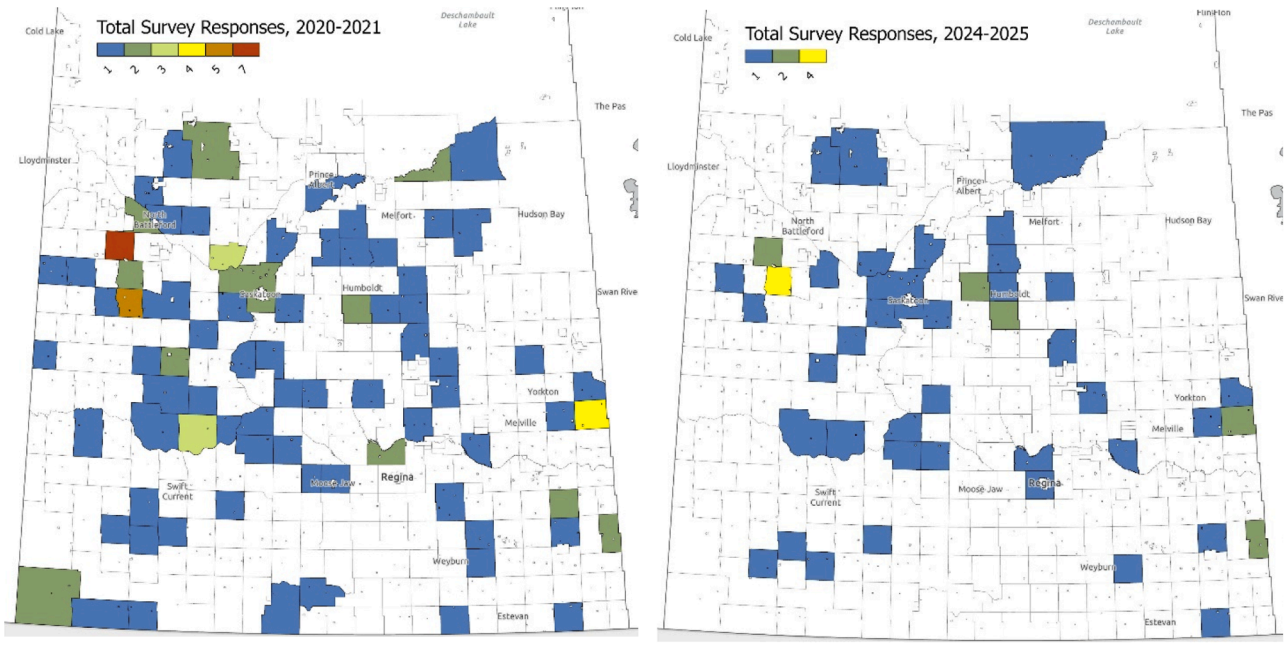

Fig. 1. Survey participant locations by RM, 2020-2021 and 2024-2025 surveys.

Table 1
Crop rotation survey participant demographics compared to 2021 Census of Agriculture.

	2020-2021 Crop Rotation Survey	2024-2025 Crop Rotation Survey	2021 Census of Agriculture
Age			
Under 35	26%	19%	10%
35-54	41%	43%	30%
55 +	33%	37%	61%
Prefer not to say	-	1%	-
Education			
Postsecondary education	58%	63%	48%
High school diploma	35%	32%	36%
No high school diploma	3%	5%	15%
Prefer not to say	3%	-	-
Collect Off-Farm Income			
Yes	40%	37%	44%
No	60%	63%	56%
Farm Size			
Under 399 acres	5%	2%	33%
400 - 759 acres	9%	2%	15%
760 - 1,119 acres	8%	8%	10%
1,120 - 1,599 acres	10%	10%	9%
1,600 - 2,239 acres	14%	14%	9%
2,240 - 2,879 acres	10%	8%	6%
2,880 - 3,519 acres	6%	19%	5%
3,520 acres or more	36%	35%	14%
Prefer not to say	2%	-	-

Source: (Statistics Canada 2021; Statistics Canada 2021; Statistics Canada 2021).

conventional agriculture practice.

Soil organic matter, the broad representation of soil health used in this analysis, was obtained from farmers' soil sampling reports. Survey participants were asked to provide the percent SOM reported in their soil sample results from any years between 1990-2024 that they had soil sampling done and the results were available to them. Of Saskatchewan survey participants, 65% provided soil sampling results for at least one of the years under study, providing an overview of the average change in SOM across the province and within the soil zones.

All analyses were completed using the Microsoft Excel Data Analysis Toolpak software. Graphs and associated regression trendlines of changes in the corresponding agricultural practices and soil conditions were created using Microsoft Excel software. Two-sample T-tests assuming unequal variance were used to determine significance of relevant indicators at the 95% confidence level ($p<0.05$). Single factor Anova tests were used to determine statistical significance of relevant indicators between the Saskatchewan soil zones at the 95% confidence level ($p<0.05$).

3. Results

Over the years studied (1991-1994, 2004-2006, and 2016-2024), Saskatchewan farmers across all three major soil zones reduced their tillage passes and the number of summerfallow fields. Across the province, the average number of annual tillage passes decreased from 1.7 between 1991-1994 to 0.4 between 2020-2024. The greatest difference was seen in the period between 1991-1994 and 2004-2006, with a decrease in average annual tillage applications of 62% ($p<0.05$). Relatedly, the average percentage of fields within the sample that were summerfallowed each year decreased by 91%, from 15% of fields between 1991-1994 to just 1.4% from 2020-2024, with 81% of this decrease occurring between 1991-1994 and 2004-2005.

Both reductions in tillage passes and summerfallow practices on Saskatchewan agricultural soils have contributed to increases in overall SOM levels. Between the first ten years of soil sample results obtained (1990-1999) and the last ten years (2015-2024), the average percent of reported SOM in the soil increased from 3.33 to 4.71, an increase of 41% ($p<0.05$). Looking specifically at the survey time periods, average reported SOM levels increased by 19% between 1991-1994 and 2004-2006 compared to 26% over the most recent 20 years. Fig. 2 illustrates this increasing trend in the average reported percentage SOM in agricultural soils.

A corresponding increase in yields of the most commonly grown crops in Saskatchewan, wheat and canola, was seen in the survey sample

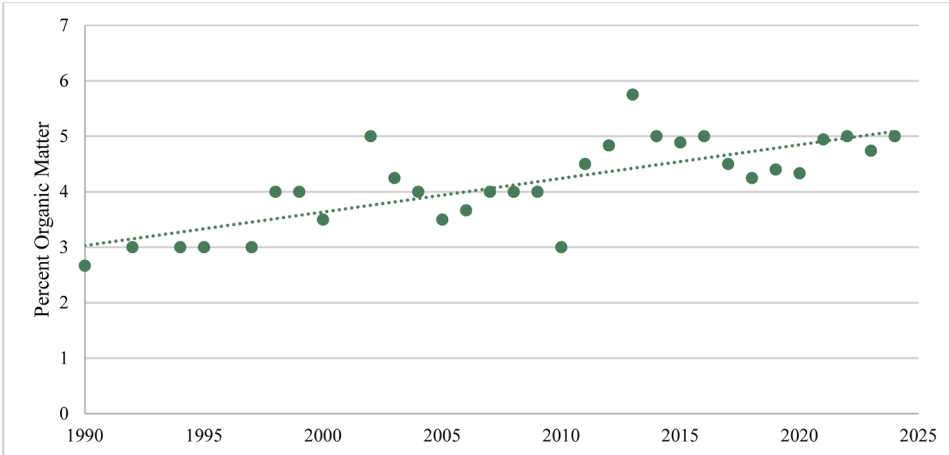

Fig. 2. Change in percent soil organic matter in Saskatchewan soils, 1990-2024.
Note: y = 0.0606x - 117.52; R^2 = 0.5716.

data over the same period. Between 1991-1994, wheat yields reported by participants averaged 34.6 bushels per acre (bu/ac), increasing by 47% to 50.7 bu/ac from 2020-2024. Similarly, canola yields increased from 27 bu/ac on average from 1991-1994 to 40.4 bu/ac between 2020-2024, an increase of 50%. The observed increase in yields cannot be credited to any single factor, but rather is a result of the system of agricultural innovations over the study period, as well as variable precipitation between crop years. These innovations include improved crop genetics as well as improvements in pesticide and fertilizer technologies. Innovations in implements have also contributed to this, such as with the ability to use variable rate applications for fertilizer across a field, based on nutrient requirements.

Fertilizer use has increased regarding pounds applied per acre of cropland between the 1990-1994 and 2016-2019 data sets. This has contributed to corresponding crop yield increases. Table 2 provides evidence of pulse and oilseed yield increases, as well as increases in the application of nitrogen fertilizer based on a previous analysis of the 1991-1994 and 2016-2019 data sets (Lika et al., 2024). A regression analysis revealed that for every 1% increase in fertilizer application, there is a corresponding 0.87% increase in crop yields. To further confirm 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.

Shifts in agronomic practices, such as the adoption of zero tillage and minimum tillage systems, contribute to improved soil productivity and increased crop yields in most soil zones (Lafond et al., 2006; Toliver et al., 2012). The removal of tillage contributes to greater nutrient retention in fields due to the reduced soil erosion, allowing fertilizer nutrients to be available for the crop, rather than being transferred to local watersheds (Dong et al., 2016). At the same time, increased yields result in greater levels of crop residues after harvest. When crop residues are left in the field, they break down and become organic matter, contributing to increasing levels of SOM. Thus, there are multiple relationships between increased crop yields and improved SOM levels; crop yields increase as a result of improved soil health and contribute to further increases in SOM.

Table 2
Change in average annual Saskatchewan crop yield and nitrogen use: 1991-1994 and 2016-2019.

	1991-1994	2016-2019
Pulse yield	27-34 bu/ac	33-42 bu/ac
Pulse nitrogen use	30-41 lbs/ac	186-196 lbs/ac
Oilseed yield	22-31 bu/ac	43-58 bu/ac
Oilseed nitrogen use	152-169 lbs/ac	171-193 lbs/ac

Source: adapted from previous research by the same research team, 21.

Because climate and soil attributes vary significantly across the province, it is helpful to examine the changes in this soil health indicator by provincial soil zone. Soil organic matter content is largely dependent on climate and its impact on soil microbial processes, resulting in the soil zones closely following Prairie climate zones (Canadian Society of Soil Science, 2020). Fig. 3 highlights the increases in SOM levels across the three provincial soil zones. The brown soil zone, situated in the southwest region of Saskatchewan, typically sees the warmest temperatures and driest agricultural conditions in the province. Soils in the brown soil zone also typically have lower organic matter levels compared to the dark brown and black or grey soil zones (Canadian Society of Soil Science, 2020). In the survey sample results, the lowest average SOM level in the brown soil zone was 2.5% in 2018 and the highest was 6.6% in 2022, which is higher than the typical range of 2.5-3.4% for this zone. The lowest average SOM level in the dark brown zone was 2% in both 1990 and 2010 and the highest was 4.8% in 2021. In the black soil zone, the lowest average SOM level was 3% in 1992, 1994, and 1997, and the highest was 5.8% in 2013. Results of a single-factor ANOVA test show that the changes in SOM levels between the soil zones were statistically significant at the 95% confidence level ($p<0.05$). There were fewer survey participants located in the brown soil zone than the dark brown and black soil zones. Consequently, soil sampling data were only provided from 2015 onward for the brown soil zone, resulting in a temporarily condensed SOM trendline.

Figs. 4-6 illustrate the relationships between changes in the number of tillage passes, percent summerfallow fields, and percent SOM in each of the three soil zones. The rate of reduction in tillage applications was consistent with no significant differences seen in tillage practices between the soil zones ($p>0.05$). Across the soil zones, average annual tillage passes decreased from three or fewer passes, on average, between 1991-1994 to less than one between 2004-2006 and onward.

In the sample results, between 1991-1994, the highest average portion of fields under summerfallow per year occurred in the brown soil zone (38%), followed by dark brown (19%), and black (9%) soil zones. A decade later, from 2004-2006, the percentage of summerfallow fields decreased to 11% in the brown soil zone, 4% in the dark brown, and 0% in the black. By 2020-2024, the average percent of summerfallowed fields was 2% or less across all soil zones, indicating the nearly complete removal of this practice from most operations (Figs. 4-6). T-tests revealed no statistical significance in the decreasing trends of summerfallow practices between the soil zones ($p>0.05$).

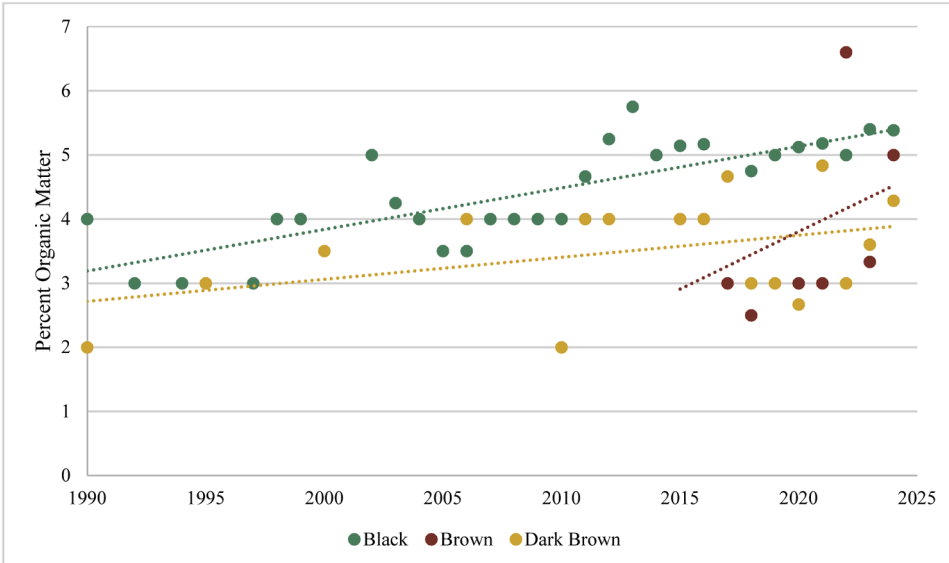

Fig. 3. Change in percent SOM across Saskatchewan soil zones, 1990-2024.
Note: Black: y = 0.0648x - 125.74; R^2 = 0.6369.
Brown: y = 0.1794x - 358.61; R^2 = 0.1665.
Dark Brown: y = 0.0344x - 65.691; R^2 = 0.1676.

Fig. 4. Changes in percent SOM, average number of tillage passes, and percent summerfallow fields in the Brown Soil Zone (1990-2024).
Note: Percent Organic Matter: y = 0.1794x - 358.61; R^2 = 0.1665.
Avg. Number Tillage Passes: y = -0.0612x + 123.7; R^2 = 0.6533.
Percent Summerfallow Fields: y = -1.2386x + 2502.1; R^2 = 0.5973.

4. Discussion and policy implications

Results of the analysis indicate that the reductions in soil disturbance that Saskatchewan farmers have adopted over recent decades have had tangible, measurable SOM improvements. With the adoption of zero tillage and minimum tillage systems, along with the removal of summerfallow practices from the majority of fields, SOM previously lost to intense cultivation is being regained across the three main Saskatchewan soil zones. Increased SOM levels have been complimented by higher yields resulting from the increase in fertilizer applications, which has the potential to generate higher volumes of post-harvest residues remaining on cropland fields. Higher yields in some crop varieties, such as wheat, do not necessarily translate into significantly higher post-harvest residues as many current wheat varieties are considerably shorter than varieties 30 years ago. Breeder development of shorter varieties in some crop kinds, such as cross breeding with dwarf varieties in wheat breeding, will result in minimal increases in total post-harvest residues (Clarke and DePauw, 1993). Additionally, crop diversity has changed with greater pulse crop acres and reduced cereal acres, where pulse post-harvest residues are considerably less than from cereal crops.

Fig. 2 illustrates that SOM levels on average are approaching 5%, which is significantly below historic SOM levels from the late 19th century. Janzen (2001) provides an extensive review of historic literature regarding SOM levels from the 1880s and 1890s across the three Prairie Provinces. Levels in Saskatchewan ranged from 5.16% and 5.57% in 1889 at Maple Creek, which is in the southwest corner of the province. Two studies from the east central part of the province indicate higher SOM levels, with Saltcoats reporting 12.74% in 1891 and 13.54% in 1897, with Yorkton reporting 13.27% in 1891 and 14.01% in 1897.

Maple Creek is in the Dark Brown Soil Zone and as illustrated in

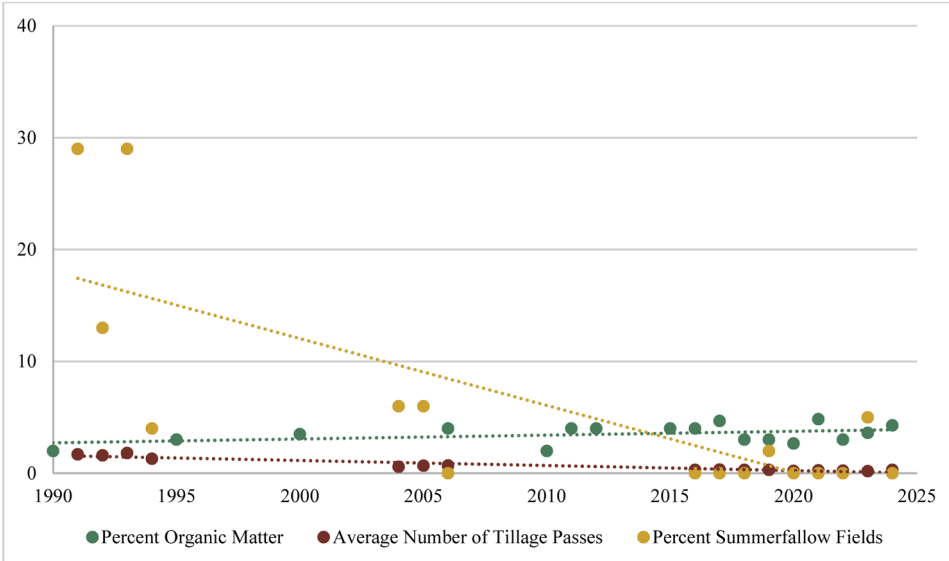

Fig. 5. Changes in percent SOM, average number of tillage passes, and percent summerfallow fields in the Dark Brown Soil Zone (1990-2024).
Note: Percent Organic Matter: y = 0.0344x - 65.691; R^2 = 0.1676.
Avg. Number Tillage Passes: y = -0.0449x + 90.993; R^2 = 0.9008.
Percent Summerfallow Fields: y = -0.5978x + 1207.7; R^2 = 0.5719.

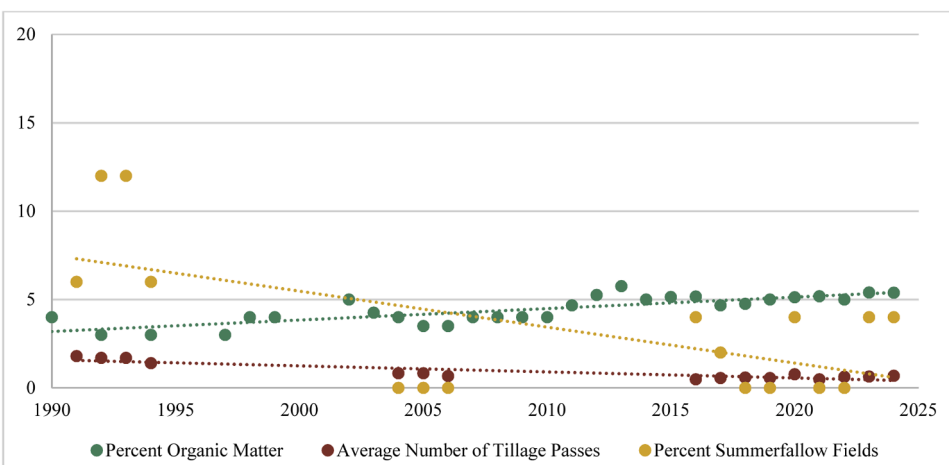

Fig. 6. Changes in percent SOM, average number of tillage passes, and percent summerfallow fields in the Black and Grey Soil Zones (1990-2024).
Note: Percent Organic Matter: y = 0.0648x - 125.74; R^2 = 0.6369.
Avg. Number Tillage Passes: y = -0.0343x + 69.83; R^2 = 0.8054.
Percent Summerfallow Fields: y = -0.2034x + 412.35; R^2 = 0.3815.

Fig. 4, SOM levels in this region are just approaching 4%. Saltcoats and Yorkton are both in the Black Soil Zone, where SOM levels are, on average, just over 5%, as illustrated in Fig. 6. Based on the historical perspective by Janzen (2001), recent SOM levels would appear to be closer to historical levels in the Dark Brown Soil Zone than those in the Black Soil Zone, where current levels are less than 50% of historic, indicating greater potential opportunity for further SOM increases in the Black Soil Zone.

The most notable differences in tillage and summerfallow practices occurred in the first decade of the study between 1991-1994 and 2004-2006. Widespread adoption of reduced tillage systems and removal of summerfallow practices had already occurred by the study period of 2004-2006. This is noteworthy in the context of national and international climate agreements made over the last ten years, such as the Paris Agreement, which uses 2005 as the baseline year (Environment and Climate Change Canada, 2020). Only recognizing shifts in greenhouse gas (GHG) emissions and sustainable adoptions since 2005 does not consider the sustainable adoptions and the resulting environmental gains that were made before this baseline year. These pre-2005 management shifts are shown in the present analysis to have significantly affected SOM levels. Using 2005 as the baseline year effectively excludes the contributions made from early adopters on the Prairies from these commitments. While it is understood that a baseline year must be chosen, it is questionable whether there are significant improvements that can be made beyond 2005 for GHG emissions in Canadian crop production while maintaining current production levels.

4.1. *2024 Senate report on soil health*

The 2024 Report of the Standing Senate Committee on Agriculture and Forestry (SSCAF) on soil health (Standing Senate Committee on Agriculture and Forestry, 2024) emphasized the need for a long-term

overarching strategy to protect and conserve Canadian soils. The report highlighted multiple key recommendations for increased soil health, the majority of which focus on creating incentives, initiatives, and programs to encourage the adoption of sustainable, long-term practices that promote improved soil health in agricultural soils and beyond. One recommendation for building soil-related incentives and initiatives important to Saskatchewan farmers indicates that early adopters should not be left behind in the implementation of tax credit and other incentive programs for adopting innovations and technologies that promote soil health (Standing Senate Committee on Agriculture and Forestry, 2024). In national discussions of agricultural sustainability over recent decades, early adopters have often been left out of incentive programs due to the choice of baseline years. The present analysis shows that management decisions made by early adopters of zero tillage and minimum tillage systems have significantly affected SOM levels in the province. The call for recognition of early adopters in the Senate Report is a crucial step in ensuring that Prairie farmers are recognized for their contributions in helping to achieve Canada's environmental goals.

The creation of a national soils institute and database is also recommended in the Senate Report to help fill the data gap on soil health and how soil health indicators are changing over time. The need for data to inform policy in the agricultural environmental space is ever-increasing as innovation and technological adoption change the ways that Prairie farms operate. The present analysis contributes to this soil health data gap by sharing field-level data on soil organic matter levels as reported by farmers; however, more detailed data on additional soil health indicators are required to draw broad conclusions on the state of soil health on the Prairies and across Canada.

4.2. Impact of GMHT cropping systems

The dramatic uptake of sustainable management practices and the resulting increase in SOM levels in the decade between 1991-1994 and 2004-2006 coincides with an important agricultural innovation that was introduced to Prairie farmers in 1995. The commercialization of GMHT canola was a major contributor to the reductions in tillage and summerfallow beginning in the late 1990s and early 2000s (Brookes and Barfoot, 2006; Smyth et al., 2024; Sutherland et al., 2021). The introduction of this innovative technology allowed for effective and economical weed control without requiring disturbance of the soil. In research conducted by Sutherland et al. (2021), Saskatchewan farmers assigned glyphosate an average factor of nine out of ten in terms of its importance in facilitating the continual removal of tillage and summerfallow from their operations.

In addition to increased SOM levels, there have additionally been reductions in soil erosion and increased soil moisture. Smyth et al. (2011) found that 86% of farmers who adopted GM canola reported reduces soil erosion, with 83% reporting increased soil moisture conservation. The Canadian Prairies experienced a decade long drought during the 1980s, which resulted in significant soil erosion, especially wind erosion. With fields having been zero tillage or minimum tillage for 20-25 years now, soil erosion is greatly reduced. With fields no longer being tilled, post-harvest residues reside on the surface and act as a layer of insulation in periods of intense heat, contributing to reduction in moisture evaporation. Zhang et al. (2022) observed that greater returns of post-harvest materials contributed to higher soil moisture. The ability to extend healthy soil moisture levels longer into the growing season during periods of above average temperatures contributes to higher yields for farmers. Soil conservation is of great importance to farmers and Saskatchewan farmers are demonstrating that the adoption of innovative technologies contribute to improved soil conservation.

With any management change, there exist tradeoffs in externalities. The shift to reduced tillage and GMHT cropping systems has contributed to improved aspects of soil health, particularly through higher SOM levels, but the tradeoff has been increasing herbicide applications. Increased use of agri-chemicals has environmental impacts, such as changes in biodiversity, aquatic and terrestrial habitats, and watersheds. However, newer chemicals used on major crops are, in general, less toxic than many of the older chemicals used Fernandez-Cornejo et al. (2014), especially glyphosate, which is an important complementary herbicide in GMHT systems. Between 1991-1994 and 2016-2019, the environmental impact of herbicides applied to crops in Saskatchewan dropped by 65%, while 45% less active ingredient was applied (Lika et al., 2024), indicating an overall decrease in the environmental impact of pesticide use despite the increased reliance on pesticides as a form of weed control.

The effective weed control provided by GMHT crops and GMHT canola in particular, are providing benefits that extend across the entire crop rotation and reduced erosion and increased moisture conservation benefit all crops being produced. There are non-peer-reviewed reports from environmental non-governmental organizations suggesting that the adoption of GM crops and continuous cropping is harming soil health, however, the evidence provided by Saskatchewan farmers soundly refutes these suggestions.

4.3. International sustainability goals

The 2030 Agenda for Sustainable Development, adopted in 2015 by United Nations Member States, includes 17 goals to provide direction on implementing strategies to improve health, education, and economic growth, reduce inequality, and preserve the environment (United Nations, 2015). Goal 15 states, "[p]rotect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (United Nations, 2015). Further, the second target of the Global Biodiversity Framework (GBF), which came into effect in 2022, encourages the restoration of 30% of degraded ecosystems by 2030 (Convention on Biological Diversity, 2025). This target pertains to both natural ecosystems and those that have been transformed, such as agricultural land. The survey results show that the adoption of GMHT crops, increased fertilizer use, and the resulting shifts in management practices in Saskatchewan have contributed to achieving both international sustainability goals. Reducing soil disturbance and increasing crop residue levels are helping to reverse soil degradation caused by decades of intense cultivation through improved SOM levels.

One of the challenges of politically-based agreements such as the GBF is that they are completely disconnected from past impacts of current practices. The GBF calls for a 30% restoration of degraded ecosystems by 2030, based on 2020. As quantified above, SOM levels in Saskatchewan increased 26% between 2005 and 2024. It can be argued that this 26% increase is a restoration of degraded soil in the province, however, this would be subject to political interpretation. This evidence reflects the danger of developing policies based on politically-based agreements that lack appropriate baseline reference points. Basing policies on unrealistic timeframes not reflecting past achievements in soil conservation poses significant threats to the continuation of economic and environmental sustainability practices.

These survey results suggest that the adoption of GM crops could contribute to improved soil health in other countries currently considering the commercialization of GM crops. The ability of farmers to remain in continuous crop, zero tillage, or minimum tillage rotations through the use of innovative technologies such as variable rate seeding, fertilizing and spraying equipment, GMHT crops, and complementary chemicals such as glyphosate allows farmers to operate sustainable crop production systems capable of improving soil health and producing improved yields. The transition from tillage as the leading form of weed control to increased reliance on herbicides provides environmental benefits unrealized in other farming systems that rely on soil disturbing practices.

5. Conclusion

Saskatchewan farmers recognize the importance of conserving and protecting the health of their agricultural soils for future generations. The widespread adoption of zero tillage and minimum tillage systems across the province has contributed to a significant trend towards increased SOM levels, recouping some of the organic matter lost to years of cultivation throughout the 1900s. Complimenting this is higher yields that are due to improved crop genetics of new varieties, as well as increased fertilizer application rates. The average percent of SOM in Saskatchewan agricultural soils has increased by 41% between the first decade under study (1990-1999) and the most recent decade (2015-2024). The reported SOM changes illustrate how changes in on-farm management practices and the adoption of innovative equipment and technologies, have contributed to regaining some of the SOM lost due to years of cultivation on Saskatchewan's arable land. The data analyzed for this article confirm the initial research hypothesis that the removal of land tillage practices and increased yields due in part to increased fertilizer applications have contributed to improving SOM levels in Saskatchewan.

These shifts in management practices towards lower soil disturbance farming have coincided with the important technological advancement of GMHT crops. The adoption of GMHT cropping systems has allowed farmers to achieve effective and economical weed control without the need for soil disturbance. The results of this analysis reveal that the continuous innovation and technological advancements in Prairie agriculture are improving the environmental footprint, in terms of soil health, in a tangible way. Based on 30 years of GMHT crop production in Saskatchewan, this technology has contributed to Saskatchewan farmers being among the most sustainable farmers in the world (Bamber et al., 2025).

The importance of soil health is being recognized on a wide scale, as shown by the 2024 Canadian Senate Report on the importance of soil health (Standing Senate Committee on Agriculture and Forestry, 2024). From an agricultural standpoint, it is positive that the maintenance of this essential asset is being recognized, and policy initiatives to encourage further steps in protecting and conserving Canadian soils are being discussed. It is important that the contributions that farmers have already made towards improved soil health are recognized, especially those of the early adopters who are often left out of policy discussions in the agri-environmental space.

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CRediT authorship contribution statement

Chelsea Sutherland: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Savannah Gleim:** Writing – original draft, Project administration, Methodology, Data curation, Conceptualization. **Stuart J. Smyth:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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