Chapter

Resiliency of Prairie Agriculture to Climate Change

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Abstract

The Prairie Region, consisting of the provinces of Manitoba, Saskatchewan, and Alberta, is a major agricultural region of Canada. Climate change will have a significant impact on its agriculture and through these changes on related industries in the region, as well as on other parts of Canada and rest of the world. This study is a synthesis of literature on various aspects of climate change—impacts, adaptation, and knowledge gaps for the Prairie Region. These impacts include potential to increase crop production through higher yields, improved livestock productivity, and higher income for producers through higher export sales. Agriculture may also expand to higher latitude areas that are currently not capable of sustaining such an activity. However, the dampening effect on the region would be through higher frequency of extreme events—droughts and floods. In spite of positive effect of climate change on the region, adaptation to climate change by producers will be virtually necessary. Producers are willing to adopt such measures, although there are major knowledge gaps in how climate change would affect and how one can adapt to it. Major uncertainties are carbon fertilization, ability of northern areas to sustain production with shifting ecozones, and impact of new pest and diseases, among others, which may affect the degree of resiliency of the prairie agriculture to climate change. This review concludes that the prairie agriculture is resilient except under prolong and intense extreme events and lack of adaptation to them.

Keywords: climate change, Canadian Prairies, economic impacts, adaptation, extreme events

1. Introduction

In its fifth assessment report [1], the Intergovernmental Panel on Climate Change (IPCC) concluded, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." This warming of the climate is commonly referred to as the climate change.

Climate change is a change in the long-term weather conditions of a region and is often used to refer specifically to anthropogenic climate change (also known as global warming). Weather records from across Canada show that every year since 1998—that is 20 years ago now—has been warmer than the twentieth century average [2]. This means that a whole generation of Canadians has never experienced what most of modern history considered a "normal" Canadian climate.

Climate change presents opportunities as well as risks for agricultural production world over and Canada is no exception to it. A warmer climate and a longer growing season could benefit many aspects of Canadian agriculture [3, 4] and provide new opportunities. However, the key here may lie in the manner in which producers adapt to the new climate and take advantage of them. Appropriate adaptations would allow agriculture to minimize the losses by reducing negative impacts and maximize profits through capitalizing on the benefits. Adoption of proper policies may also play a critical role in not only minimizing the losses from climate change but also providing proper incentives for adaptation to it, thereby becoming more resilient to climate change.

1.1 Adaptation and resilience

Under a changing climate, society must make adjustment, called adaptations. If such adaptations are done properly, the industry may become more resilient to climate change. The term resilience has Latin roots, *resilire* (meaning 'to jump back'), and can be defined as a measure of the resistance of systems and of their ability to absorb change and disturbance and still maintain the same relationship between populations or state variables [5]. Hammond et al. [6] have defined it as the amount of change a system can undergo, while retaining similar function and structure. Resilience is closely related to the notions of sustainability but emphasizes unpredictable dynamic environments [7]. Achieving resilience is through improving adaptive capacity, the ability to react effectively to change over time in order to maintain a desirable system state.

1.2 Objectives of the study

This study is based on a review of available literature for the Prairie Region and other similar parts of the world. Its major objective is to review impacts of climate change on agriculture in the Prairie Region in the context of resiliency. Both direct and indirect impacts are included in the review along with adaptation measures that could be adopted to reduce the negative impacts of climate change and to create resiliency.

2. Description of the study region

Agriculture (including crop and livestock enterprises) is an important industry in the Prairie Region, which includes three provinces: Manitoba, Saskatchewan, and Alberta (**Figure 1**). The region is land-locked, located in the western part of Canada. In 2017, over half of the agricultural activities (measured in terms of farm cash receipts) originated in the region (**Figure 2**). In fact, these three provinces could represent the epicenter of Canada's agricultural production, as over half of the Canadian farm income is generated in this region. However, in terms of land base devoted to agricultural pursuits, the region is the most important one within Canada, as over two-fifth (84.4%) of crop and pasturelands is in the region (**Table 1**).

Climate is an important factor that not only determines the geographical limits to agricultural production in a region but also produces year to year variability in crop yields, productivity of livestock enterprises, and through these ultimately in economic returns to producers. Because of climate- and soil-related limitations, not all land area in the region can be devoted to agriculture. For example, in Saskatchewan, of the total land area of 57 million ha, only 26.6 million ha

Figure 1.
Map of Canada showing location of Prairie Provinces. Source: [8].

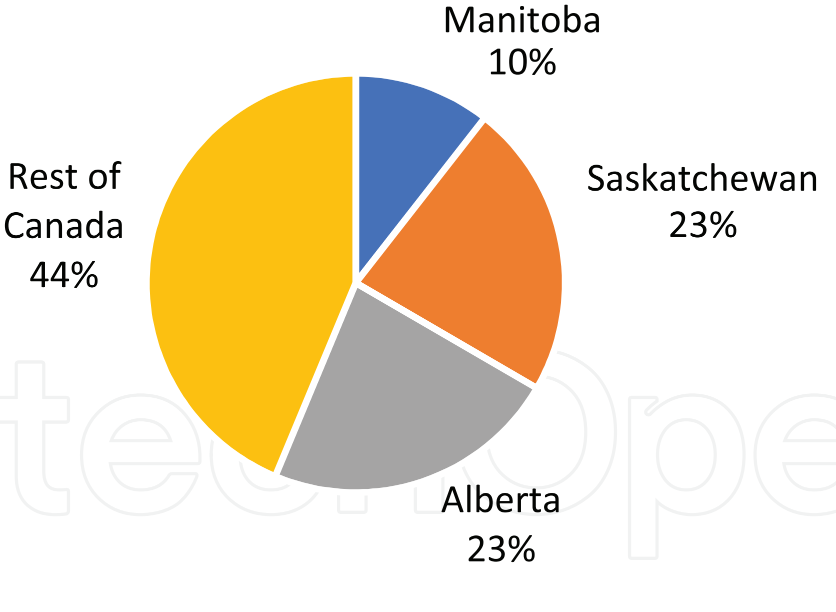

Figure 2.
Share of Canadian farm cash receipts by regions, 2017. Source: Data obtained from [9].

(or 46.6% of the total area) is under farms or agricultural operations. Most of the agricultural area is located in the southern portion of the region. Manitoba has most farms with cattle and field crops, whereas in Saskatchewan, field crops dominate. Alberta is a large producer of cattle and other livestock, besides grain and oilseeds. Climate change could bring forth many negative/positive impacts on the agricultural economy of the Prairie Region. One such factor, which is particularly relevant to the semiarid regions of Canada, is the occurrence of droughts. These events can have a highly negative impact on agriculture and through that on the rest of the economy.

Provinces/ region	Total area in 1000 ha			Percent of Canada		
	Total cropland and pastureland	Cropland including summer fallow	Tame and native pasture-land	Total cropland and pasture-land	Cropland including summer fallow	Tame and native pastureland
Manitoba	6450	4707	1743	11.1	12.2	9.0
Saskatchewan	23,470	16,963	6507	40.4	43.8	33.6
Alberta	19,097	10,484	8613	32.9	27.1	44.5
Prairie Region	49,017	32,154	16,863	84.4	83.1	87.2
Canada	58,027	38,342	19,342	100.0	100.0	100.0

Source: [10].

Table 1.
Regional characteristics of agricultural production in Canada, 2016.

3. Study methods

In order to organize the review of literature, a conceptual framework of direct and indirect changes hypothesized to climate change was developed (**Figure 3**). A change in the climate would first alter various climate attributes. These may include change in average temperature, change in amount of distribution of

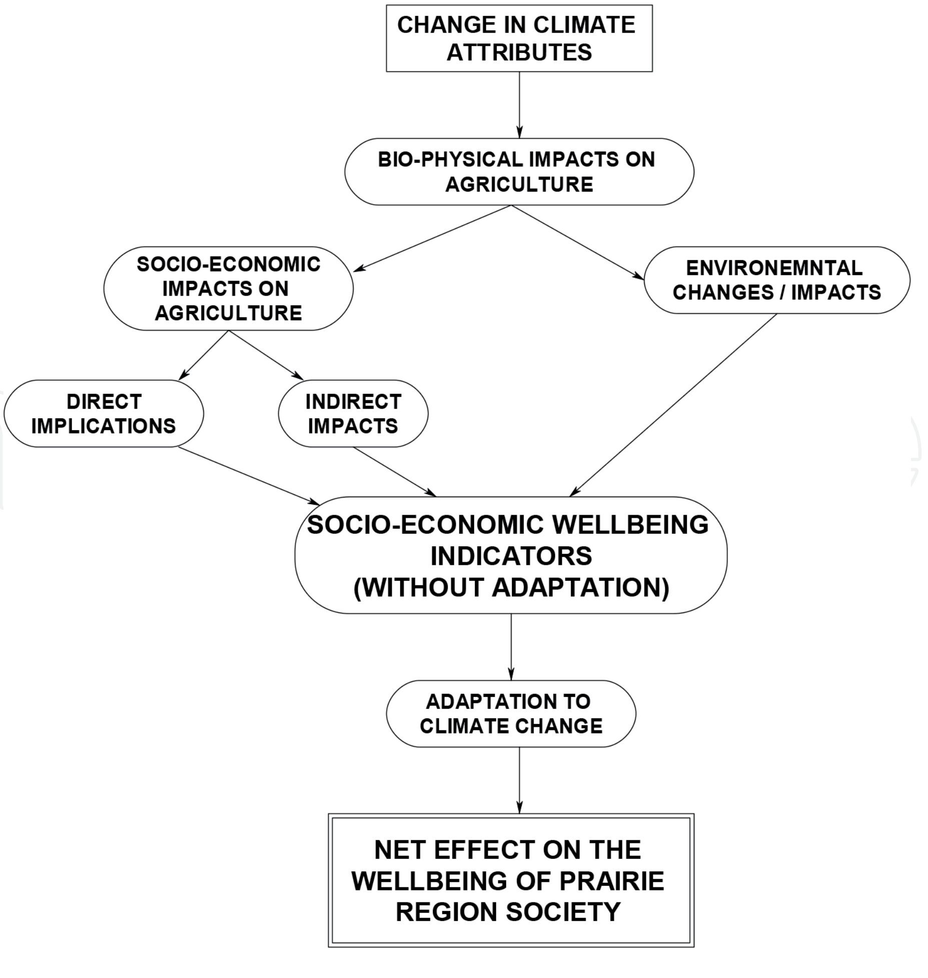

Figure 3.
Conceptual framework for estimating impacts of climate change on society.

precipitation (including the form of precipitation—snow vs. rain), and occurrence of extreme events in a region. These changes would directly affect the Prairie Region, particularly agricultural production. Some of these would include biophysical changes, such as change in yield, introduction of new crops, and suitability of a region for agricultural production, among others. These biophysical changes would translate into socioeconomic changes, first on farms and the agriculture industry, and then through economic linkages to other sectors of the economy, they would affect the entire regional economy. Since the region has a surplus for many crops and livestock products, its economic fortunes also depend upon agricultural commodity exports to other countries. As climate change affects other parts of the world, it may create food security issues in these countries and thus create new export opportunities for the region.

4. Results

4.1 Impacts on climate attributes

Climate change would alter several climate-related attributes that might affect the Prairie Region. These may include [11] (1) change in the temperature, (2) change in the level of precipitation and its form (more precipitation occurring as rain than snow), (3) inter-year variability in precipitation, and (4) change in the frequency of extreme events. In addition, an indirect economic effect on the region could be through sea level rise affecting agricultural production in other countries, affecting their food self-sufficiency.

Although global warming would affect all parts of the world, higher impacts are predicted for the northern hemisphere (which includes the Prairie Region). This region is expected to become warmer during the fall and winter seasons. In the agricultural belt, increases of 2–4°C will be experienced during the growing season [8]. During the September to November period, an increase of 2–3°C will be more common all over southern agricultural belt in Canada by 2041–2070. Increased temperatures would result in an increase in the duration of the growing season for crops and early seeding dates. Precipitation in the agricultural region is not projected to increase much but its variability is expected to increase. By the 2080s, projected precipitation increases may range from 0 to 10% in the far south, which through enhanced evapotranspiration will result in a moisture deficit during the growing season [12]. Associated with higher temperatures, some of the precipitation in the region would come as rain rather than snow. Depending on the saturation status of the soils, some of the precipitation would result in runoff and may create reduced moisture available for the crops. In addition, runoff from agricultural lands could create environmental problems such as eutrophication of water bodies.

Studies [13–16] have shown greater drought frequency and severity in the region mainly due to increasing temperatures. In the future, there would be a higher persistence of multiyear droughts in central and southern portions of Canadian Prairies. Multiyear severe droughts could have an effect on soil moisture and may eventually make some parts of the region not suitable for agriculture. More recently, flooding has also been a major occurrence. This creates problems for farmers not only through soil erosion but also through late seeding or totally no seeding in some areas. In Manitoba, for example, there is evidence to suggest that recent agricultural losses from flooding increased by over 300% since the historical period (1966–2015) [15].

4.2 Biophysical impact of climate change attributes

4.2.1 Impact on water resources

Water resources in the Prairie Region would be affected through a culmination of changes in key variables governing the hydrological cycle: temperature, evapotranspiration, precipitation, and snow and ice. Since water in most prairie rivers is provided, in part, by melting of glaciers located in the Rocky Mountains (supplemented with seasonal rainfall), higher temperature coupled with evapotranspiration will play an important effect on the water cycle. According to [17], studies based on hydrological models suggest that annual streamflow of the South Saskatchewan River may range from an 8% increase to a 22% decrease, with an 8.5% decrease being an average prediction. In addition, this study suggested that there is not a dramatic drying of the prairies to be anticipated under climate change and that in some cases streamflow will increase for certain climate scenarios and under moderate degrees of climate change.

Another factor that may affect water resources is the form of precipitation. It is expected that due to warmer winters, much of the current winter precipitation, which now falls as snow, could be in the form of rainfall. This has implication for soil moisture for crop and thus for crop growth. Winter warming will reduce snow accumulations in alpine areas and across the prairies. This will cause a decline in annual stream flow and a notable shift in stream flow timing to earlier in the year, resulting in lower late season water supplies. Continued glacier retreat will exacerbate water shortages already apparent in many areas of Alberta and Saskatchewan during drought years. Lower stream flow would have an impact on the output of hydroelectric plants, as well on the capacity of the irrigation reservoirs to provide water to producers.

Groundwater is the source of potable water for about 30% of Manitoba residents, 22% of Albertans, and 43% of Saskatchewan's population [18]. Future groundwater supplies will be affected in a similar manner as changes in surface water flows and frequency of extreme events. Increased rainfall in early spring and late fall will enhance recharge if soil water levels are high; otherwise, water will be retained in the soil, benefiting ecosystem and crop productivity. Drier soils due to higher rates of evapotranspiration result in decreased recharge, which would lead to a slow but steady decline in the water table in many regions.

Climate change may also have an impact on prairie wetlands. Many of these may be reduced in size or even totally dry up, which may have some impact on groundwater quality as well as recharge capacity.

Some studies, such as [19], have reported that the excess heat caused by climate change may influence the effectiveness of inputs for crops; for example, fertilizer productivity may be reduced. This may lead to reduced fertilizer use, which may be good news for water quality damages, such as nitrates in groundwater, eutrophication, among others, but would be bad news for crop yields.

4.2.2 Effect of climate change on soil moisture

Under climate change, soils are projected to be slightly moister and warmer in winter, but large increases in soil temperature and large decreases in soil water content are projected during the growing season. During the warmer summer conditions, the level of evapotranspiration will increase along with demand from plants. Both of these can result in a drought stress, particularly when soil moisture level is low [20]. Depending on the frequency and intensity of droughts, soil moisture is expected to decrease and the semiarid areas of the southwestern Saskatchewan and southeastern Alberta (an area known as Palliser Triangle) will increase.

4.2.3 Other environmental effects related to climate change

Extreme dry condition over a prolonged period would have other environmental effects. In fact, the implication of more frequent and widespread droughts is that they place a larger area at risk of desertification more often unless counteracting management strategies are enacted [21]. Development of the sand dunes in southwestern Saskatchewan has been suggested to be an effect of prolonged droughts in the region (see more details in [22]). This would result in a loss of agricultural land for meeting growing demands for humans and animals.

4.3 Direct impacts of climate change on agriculture

4.3.1 Biophysical impacts on crop production

Due to enhanced evapotranspiration, driven by higher temperatures, many regions will experience a moisture deficit despite higher (but variable) amounts of precipitation. Water stress during critical times for plants (e.g., flowering) is especially harmful and would affect plant growth and productivity. Yield responses are sensitive to climatic change and location and tend to reduce the beneficial effects stemming from elevated carbon dioxide (CO_2) levels [23]. Details of changes in yields of selected crops in Canada (applicable to the Prairie Region) are presented in **Table 2**.

Estimates of future yields under climate change have been variable depending on the climate model used, location, and global warming levels. Another uncertainty is created by the positive effect of higher level of CO_2 in the future. A study by [23] has reported an increase in the yields of canola and wheat with increase in global warming, while maize (corn) yield was simulated to increase or slightly decrease depending on the characteristics of the currently grown cultivar and differences among the crop models. The same study also indicated that future warming accompanied by increased CO_2 concentration would remain beneficial to crop yields at the global warming level of 2.0°C for Canada.

Agriculture in the Prairie Region could benefit from warmer and longer growing seasons and a warmer winter. Climate change may also bring opportunities, which could increase productivity and allow cultivation of new and potentially more profitable crops and tree species. A study [27] has indicated that under the projected changes in climate, area allocated to wheat will continue to decrease into the future by 2.7–4.6% in various soil zones, while the area left to summer fallow is projected to increase. The choice of wheat is preferred over pulses, feed, and forages, while the choice of specialty oilseeds (flaxseed, mustard seed, and canary seed) is projected to become preferred over wheat in the future. Change in crop mix has been suggested [28], but it still will be dominated by wheat, barley, and canola. Producers under the changed climate may also introduce some new crops, such as:

Pulse crops: Pulse area is likely to increase in the drier, more arid growing environments that are expected in 2050.

Soybeans: The transition to larger soybean area in the prairies is already underway with former marginal areas in southern Manitoba and Saskatchewan now growing the crop in a regular rotation.

Corn: The movement of corn is also underway to parts of southern Manitoba and southern Alberta, but the transition is expected to take a longer time than

Crop	Model*	Global warming level in °C	Yield increase percentage of 2006–2015 mean	
			With CO_2 fertigation	Without CO_2 fertigation
Canola	DayCent	1.5	1.5	−2.8
		3.0	2.4	−13.4
	DSSAT	1.5	6.1	−1.0
		3.0	7.7	−15.5
Wheat	DayCent	1.5	1.9	−2.3
		3.0	4.6	−11.3
	DSSAT	1.5	6.1	2.1
		3.0	22.8	1.8
Maize (Corn)	DayCent	1.5	−0.7	−1.5
		3.0	−5.6	−9.0
	DSSAT	1.5	3.0	1.2
		3.0	−4.8	−11.8

DSSAT is the Decision Support System for Agrotechnology Transfer. For details, see [24].
Source: Adapted from [25].
**DayCent is a daily time series biogeochemical model used in agroecosystems to simulate fluxes of carbon and nitrogen between the atmosphere, vegetation, and soil and is a daily version of the CENTURY biogeochemical model. For details, see [26].*

Table 2.
Projected future changes in crop yield under rain-fed conditions with and without carbon dioxide fertigation.

soybeans. Corn will also be limited by the dryness in parts of the southern prairies. Corn has large moisture requirements to produce economically attractive yields.

Sorghum and millet: Sorghum and millet are two possible crops to move into the drier areas of the prairies in 2050. These crops represent a possible feed grain for the driest areas, but sensitivity to frost will limit area even with increased growing season [25].

Negative impacts may result from changes in the timing of precipitation, increased risk of droughts and associated pests, and excessive moisture. Because of these positive and negative factors, crop yields will vary from region to region.

4.3.2 Livestock production

Temperature is considered the most important bioclimatic factor for livestock [29]. Warmer temperatures may create benefits and challenges to livestock operation in the Prairie Region [30]. The major benefit would be through higher winter temperatures, which would lower feed requirements, increase survival of the young, and reduce energy costs [31]. Hot environment impairs production (growth, meat and milk yield and quality, egg yield, weight, and quality) and reproductive performance, metabolic and health status, and immune response [32]. However, these changes would also produce challenges for livestock producers in the form of new pests and diseases for animals, and alien species for grasslands and pastures. The warming climate would bring challenges during summer months, when heat waves can kill animals, particularly chickens [33]. Heat stress can also affect the productivity of dairy animals, the meat quality for beef animals, and reproduction (particularly for dairy animals). In some areas, the process of desertification may reduce the carrying capacity of rangelands (as suggested by [34]) and the buffering ability of agro-pastoral and pastoral systems.

4.3.3 Socio-economic effect of extreme events on agriculture

Results from studies on the economic impacts of climate change on prairie agriculture are highly variable from region to region and from study to study. Some studies suggest that overall economic consequences will be negative and small, whereas others indicate positive and large impacts.

Socio-economic impacts of climate change-induced changes have been estimated to be positive. A Manitoba study [35] estimated that changes in crop revenues under current economic/technological conditions will range from a 7% loss in Alberta under one scenario to an 8% increase in Saskatchewan under a slightly different scenario. Manitoba, the least water-deficient province, has been projected to benefit from warming as producers shift to higher value crops, resulting in an increased gross margin of more than 50%. Many studies have predicted increased land values in the Prairie Region under climate change. Similarly, for Saskatchewan, a study [36] reported that climate change is beneficial for Canadian Prairie agriculture except for some southeast regions of Alberta. Comparing the results from direct impacts of climate and price changes on land value with the results from indirect impacts through area response estimation reveals that direct impacts would increase land values by 31%. Ayouqi and Vercammen [37] have suggested similar results, who applied three different climate change scenarios. They reported that except for the north part of Saskatchewan and the west part of Alberta in the medium climate change scenario, all other cases show increase in the farmland value. In fact, the farmlands of Canadian Prairies were estimated to gain a value between $1.14 and $4.1 billion annually (based on the estimation model and scenario).

Extreme events can have devastating impacts on crop yields and through these on the rest of the regional and national economy. The Prairie Region (in fact other parts of Canada as well) experienced a major back-to-back drought during 2001 and 2002. Estimated impacts of these droughts [34] indicate that crop yields were as little as half of average yields during normal or more suitable growing conditions. Repercussions of these droughts were severe and far-reaching, including: (1) Agricultural production levels, through crop production losses, were devastating for a wide variety of crops across the Prairie Region, particularly in 2001. Total value of production dropped an estimated $3 billion for the 2001 and 2002 drought years, with the largest loss in 2002 at more than $2.2 billion. (2) The Gross Domestic Product fell some $4.5 billion for 2001 and 2002, again with the larger loss in 2002 at more than $3.1 billion. (3) Employment losses exceeded 27,883 jobs, including nearly 17,803 jobs in 2002. (4) Net farm income was negative or zero for several provinces for the first time in 25 years. (5) Livestock production was especially difficult due to the widespread scarcity of feed and water. Many producers culled their herd after the first year of the drought. (6) Water supplies that were previously reliable were negatively affected, and several failed to meet the requirements. (7) Multisector effects were associated with the 2001–2002 drought, unlike many previous droughts that affected single to relatively few sectors. Impacts were felt in areas as wide-ranging as agricultural production and processing, water supplies, recreation, tourism, health, hydroelectric production, transportation, and forestry. (8) Long-lasting impacts included soil and other damage by wind erosion, deterioration of grasslands, and herd reductions. (9) Several government response and safety net programs partially offset negative socio-economic impacts of the 2001 and 2002 drought years [34]. In the future, drought frequency has been predicted to

Overall impacts	Major impact type and/or limitations
Opportunities for agriculture may result from continued expansion of the growing season, increased heat units, and milder shorter winters.	Agriculture could benefit from several aspects of warming climate, depending on the rate and amount of climate change and ability to adapt.
Adoption of new crops would change the nature of diversification of the region.	Results of assessments are wide ranging and depend upon the climate scenarios, impact model used, scale of application, assumptions made, and how adaptation is incorporated.
Regions would become more vulnerable to droughts and floods.	Region is susceptible to droughts and floods, and their frequency is expected to increase under climate change.

Source: Adapted from [11].

Table 3.
Sensitivity of prairie agriculture to climate change.

increase under climate change; as projected, yields of various crops would decrease, thereby increasing the vulnerability of producers, particularly in semiarid regions of the prairies.

In addition to droughts, flooding of agricultural lands would also increase under climate change. Already, such events have occurred in various parts of the Prairie Region, affecting crop production. In Manitoba, for example, 2016/2017, the excess moisture losses accounted for 71% of total crop losses estimated at $198.7 million [15]. Similar estimates for other two provinces are not available.

Although overall studies have been positive about impact of climate change on prairie agriculture, increased frequency of extreme events may dampen these beneficial impacts somewhat. A summary of these impacts is shown in **Table 3**. The region would have new opportunities open under the changed climate and some new crops may help the region in diversifying the regional agriculture mix. However, increased frequency of droughts and floods may make some regions more vulnerable in the future.

5. Indirect impacts of climate change on prairie agriculture

Economics of crop production in Canada will be a joint outcome of changes within Canada and those outside the Canadian boundaries (in both the exporting and importing countries). International markets will play an important role in determining the economic impact of climate change on the Prairie Region agriculture. As most of the crops are sold in the international market place, their prices would be significantly influenced by conditions not only within Canada but also in the rest of the world. Coupled with increased export levels, these changes could have a profound impact on the economic situation in the region. Climate change would affect other parts of the world differently as shown in **Table 4**. Different areas of the world would be affected differently depending on the degree of global warming. For example, a very mild warming (say 1°C) would bring moderate increase in cereal crop yields, but a major warming (5°C or higher) would have catastrophic effects.

A further review of the changes, based on [38], suggests:

i. For US agriculture, most crops would show gains in crop yields to certain thresholds of temperature increase, which may increase their potential for exports. This is different from the impacts on crop yields in Australia, where a reduction

Temperature rise (°C)	Impact on water resources	Impact on food
1	Small glaciers in the Andes disappear completely, threatening water supplies to people.	Moderate increases in cereal yields in temperate regions.
2	Potentially some 20–30% decrease in water availability in some vulnerable regions (e.g., Southern Africa and Mediterranean).	Sharp decrease in yields in tropical regions (5–10% in Africa).
3	In Southern Europe, serious drought occurs once in every 10 years; 1–4 billion more people suffer water shortages, while additional 1–5 billion gain water, which may increase flood risk.	Additional 150–500 million people at risk of hunger if carbon fertilization is weak. Agricultural yields in higher latitudes likely to peak.
4	Potentially some 30–50% decrease in water availability in Southern Africa and Mediterranean.	Agricultural yields decline by 15–35% in Africa and entire regions out of parts of Australia.
5	Possible disappearance of large glaciers in Himalayas, affecting one-quarter of China's population and hundreds of millions in India.	
More than 5	Catastrophic effects. Hard to capture by present-day models.	

Source: [38].

Table 4.
Highlights of possible climate change impacts on water and food in the world.

is predicted. This would somewhat reduce Canada's competition in some cereal export market, notably wheat. European countries are also expected to have a decrease in production, although results may vary from country to country. Exact details on the Argentinean situation were not found in the literature.

ii. On the developing countries scene, studies suggest a decrease in the potential production. Given that demand in many of these countries, caused primarily by population growth, would most likely increase, potential for Canada to export would likely exist.

iii. Canada is a major exporter of grains and oilseeds (and of pulses recently). The impact on Canadian agriculture, therefore, would also result from changes in the crop production and their demand in the rest of the world under future climate.

6. Adaptation options under climate change

Prairie producers are highly adaptable to changing conditions. However, such adaptations are sometimes complex and often costly. Under climate change, there may exist some beneficial changes (such as higher level of pulse production, increase in the area under cultivation, and its productivity), but if the rates of these change are faster than producers have experienced, they may pose more difficulties for adaptation. For example, production of new crops may become ergonomically feasible, but whether producers would be able to adapt sufficiently or quickly enough to these new realities is somewhat uncertain. Financial requirements for making such adaptations may be a major constraint.

A synthesis of research on adaptation options for agriculture has identified four main categories [39]: (i) technological developments, (ii) government programs and insurance, (iii) farm production practices, and (iv) farm financial management. In addition to these 'direct adaptations,' there are options, particularly information provision that may stimulate adaptation initiatives. Most adaptation options are modifications to on-going farm practices and public policy decision-making processes with respect to a suite of changing climatic (including variability and extremes) and nonclimatic conditions (political, economic, and social) [39]. Migration by producers has also been seen as an adaptive measure for extreme events. After the prolong droughts of 1930s, many prairie producers in southwest Saskatchewan left for better agricultural regions. Such behavior is consistent with the concepts of vulnerability, exposure to risk, and adaptive capacity, as developed in the climate change research community [40].

Alberta Agriculture [41] suggests that if conditions are drier than usual, producers might (i) expect concerns with lower than usual seed germination and/or plant growth, lack of feed, and shortage of water; (ii) conduct small area tests on new crop types that take advantage of drought tolerance; and (iii) put animals on a rotational grazing program to allow grazing land to rest and recover. The Saskatchewan [42] Strategy for climate change specifically commits to develop and implement an offset system that creates additional value for actions that result in carbon sequestration or reduced emissions, especially from soils and forests.

Other systems, such as mixed systems and industrial or landless livestock systems, could encounter several risk factors mainly due to the variability of grain and pasture availability and cost, and low adaptability of animal genotypes. Regarding livestock systems, optimizing productivity of crops and forage (mainly improving water and soil management) and improving the ability of animals to cope with environmental stress by management and selection could be the best adaptive measures. For an Alberta mixed farm, reported by [43], beef herd adaptation strategy affected farm profits more and costs less. Maintaining the herd size and with regular feeding plan, and purchasing extra fees provided the best adaptation. To guide the evolution of livestock production systems under the increase of temperature and extreme events, better information is needed regarding biophysical and social vulnerability, and this must be integrated with agriculture and livestock components.

Shelterbelts also provide several environmental benefits to the society under climate change. One of the most important ecosystem values from shelterbelts is their capacity to sequester carbon (C) [44]. Six major species of tree and brush used for this purpose were examined in this study. At maturity, these trees can sequester a large amount of carbon. For example, a hybrid poplar can sequester 3–5 t of C per year, whereas a Caragana shrub can store only 1.3–2.7 t of C per year (**Table 5**). However, the amount of C stored in the younger trees would be lower but eventually the amount would reach the levels shown in **Table 5**. In addition, shelterbelts also sequester carbon in the soil and in the understory.

If one uses the 2022 price (as fixed by the Government of Canada) of $50 per t of C, a hybrid poplar tree is worth $150–250 to the society. Unfortunately, this value is not internalized in the decision of the landowner since at present they do not receive any compensation for the stored or sequestered carbon. Under these conditions, decision to maintain shelterbelts on farms may be discouraged since they do not enter into their economic decision-making. Policies have to be developed to compensate the producer for the loss of this revenue [45].

Irrigation is one of the best adaptive measures under drought conditions [46]. In addition to stabilize production over the drought period, they increase returns from crop production and help mixed farms maintain livestock activities through forage production [47]. In addition, the level of nonagricultural sectors is also higher due to availability of water and its backward and forward linkages [48].

Type of shelterbelt	Name of the plant	Amount of carbon sequestered in mega grams per year per ha	
		Low value	High value
Tree	Hybrid poplar	3.29	5.18
Tree	Scots pine	1.44	3.26
Tree	White spruce	2.24	4.13
Tree	Green ash	2.02	3.92
Tree	Manitoba maple	2.80	5.26
Shrub	Caragana	1.31	2.67

Source: [44].

Table 5.
Level of carbon sequestered by shelterbelts by type.

There are many potential adaptation options available for marginal change of existing agricultural systems, often variations of existing climate risk management [49], but their implementation is likely to have substantial benefits under moderate climate change for some cropping systems, and there are limits to their effectiveness under more severe climate changes.

7. Knowledge gaps and areas for future research

Estimates of climate change impacts on crop production are wide ranging. Of course, different studies use different assumptions about the nature of key climate variables, along with assumptions of crop type, seeding dates, fertilization, and irrigation. Many other factors, such as insects, diseases, and weeds, would also change because of climate change. Our knowledge of these changes is very weak. Furthermore, much of the Canadian research has concentrated on cereals and to a limited extent on oilseeds (mainly canola). Research on other oilseeds, forages, fruits, and vegetables (including potatoes) has been less extensive. This is a serious gap in our knowledge for climate change impacts on crop production.

One of the changes associated with climate change is the level of atmospheric carbon dioxide. Under these conditions, a situation of carbon fertilization may occur, which may increase some crop yields (particularly for plants using the C3 carbon-fixation pathway, like wheat or canola). Higher levels of atmospheric CO_2 may also improve water-use efficiency. However, the picture is complex, since weeds may also be more vigorous under a carbon-enriched atmosphere. Warmer and longer growing seasons could be positive for crop growth and yield. However, very little research has been done in the context of the Prairie Region.

Livestock production would be affected by availability of forages and direct effect through feed efficiency. Grassland production is limited by moisture supply. Although a drier climate would suggest declining production and grazing capacity, actual changes in grassland production are likely to be modest, given a longer growing season, reduced competition from shrubs and trees, and increases in warm-season grasses that have higher water-use efficiency [50].

Northward shift of climate congenial to agricultural production has been predicted for future. However, for the Prairie Region, the exact nature of this change is not known. Furthermore, to what extent this change would translate into profitable agricultural production has yet to be researched.

Most past studies have taken into account effect of a change in temperature and total precipitation. No study was found that had included the effects of changes in the distribution of precipitation or in the form of precipitation (snow vs. rain). Other changes induced by climate change, such as pollination, heat stress days, and asymmetry in day and night temperatures, were also not included in these studies.

A study considering all of these factors together in an integrated framework is needed. This study must cover all regions of Canada and employ comparable set of assumptions with respect to climate change and related factors. There is a need for an integrated bio-physical-socio-economic assessment of climate change impacts for all regions of the prairies. Scope of the investigation needs to be national, regional, and international in nature since all these factors would shape the nature of impacts under the changed climate and the adaptation measures for prairie agriculture.

On the international aspect of climate change impacts, very few studies (since the 2005 study by [51]) were found that have reported implications of these changes in production and demand in various parts of the world and/or on trade flows. There hasn't been an assessment of impacts of these changes for the exports of agricultural products from Canada. There is a need to examine the potential for Canadian exports and imports of various crops under the changed demand and supply conditions around the world induced by climate change.

For purposes of implementing adaptations to climate change in agriculture, there is a need to understand the relationship between potential adaptation options and existing farm-level and government decision-making processes and risk management frameworks better. The relationships that determine technology development are somewhat unclear and more research is needed to understand these factors. Historically, federal and provincial governments have responded to drought with safety net programs to offset negative socioeconomic impacts [52] and, more recently, through development of drought management plans. More intense and longer droughts will be expensive challenges to safety net programs. Soil conservation is a prime example of a 'no regrets' strategy, since preventing soil loss is beneficial whether or not impacts of climate change occur exactly as projected. The Permanent Cover Program, administered by the Government of Canada, has reduced sensitivity to climate over a large area. The move in recent decades to more efficient irrigation techniques has dramatically increased on-farm irrigation efficiencies. However, the continued loss of water from irrigation reservoirs and open channel delivery systems due to evaporation, leakage, and other factors indicates the need for further improvement in the management of limited water resources. More research is needed on appropriated adaptation measures under the frequent extreme event occurrence.

8. Conclusion: resiliency of agriculture in the Prairie Region

As a high-latitude country, warming is more pronounced in the Prairie Region, which would result in longer frost-free seasons, higher degree-days, but more frequent extreme events (droughts and floods). Alberta could benefit the most from increased summer and winter precipitation, while Saskatchewan and Manitoba would experience little change or small increases. Warmer temperatures could also mean lower energy costs for farmers, as well as benefit livestock production in the form of lower feed requirements and increased survival rates of the young animals.

Prairie farmers are highly adaptive. Past changes, such as introduction of zero tillage, reduction in summer fallow area, and introduction of new cultural practices, are all indicative of this. If climate change were slow, producers would be able to adjust through proper adaptation measures. However, government policies have to be developed to assist producers in making these choices. The biggest threat to resiliency would be through occurrence of intense and longer drought periods.

Climate change could improve soil quality by enhancing carbon sequestration through "carbon agriculture," which includes no-till farming (where you grow things year-to-year without disturbing the soil), cover crops (which help spur microbial activity in the soil), and a grazing technique, such as rotational grazing. Changes to land-use through annual crop production, perennial crops, and grazing lands could all contribute to reducing greenhouse gas emissions.

Warmer temperatures also mean warmer summers, which could be problematic for livestock producers who have to deal with heat-wave deaths. Reduced milk production and reproduction are other impacts in the dairy industry, as well as reduced weight gain among beef cattle. Higher levels of atmospheric carbon dioxide (CO_2) and an increase in the use of pesticides and pathogens in livestock and crops can lead to increased weed growth. Under climate change, farmers may have a better choice of crops, which may lead to diversification, and thus assist in making agriculture resilient to climate change [53]. Cultural practices under the purview of climate-smart agriculture could also transform and orient agricultural systems to resilience under the new realities of climate change [54].

While there is a lot of uncertainty surrounding the future of Canada's agriculture industry, one thing is clear: we are likely to see more extreme weather events and higher average temperatures. Farmers must look at environmentally friendly farming practices to adapt to the effects of climate change and stay in business, thereby creating a resilient agriculture industry.

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