Farming the Future:

Agriculture and climate change on the Canadian Prairies

IISD REPORT

Julia Laforge
Vanessa Corkal
Aaron Cosbey

IISD
International Institute for Sustainable Development

November 2021

International Institute for Sustainable Development

The International Institute for Sustainable Development (IISD) is an award-winning independent think tank working to accelerate solutions for a stable climate, sustainable resource management, and fair economies. Our work inspires better decisions and sparks meaningful action to help people and the planet thrive. We shine a light on what can be achieved when governments, businesses, non-profits, and communities come together. IISD's staff of more than 120 people, plus over 150 associates and consultants, come from across the globe and from many disciplines. With offices in Winnipeg, Geneva, Ottawa, and Toronto, our work affects lives in nearly 100 countries.

IISD is a registered charitable organization in Canada and has 501(c)(3) status in the United States. IISD receives core operating support from the Province of Manitoba and project funding from governments inside and outside Canada, United Nations agencies, foundations, the private sector, and individuals.

Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700
Website: www.iisd.org
Twitter: @IISD_news

Farming the Future: Agriculture and climate change on the Canadian Prairies

November 2021

Written by Julia Laforge, Vanessa Corkal, and Aaron Cosbey.

Acknowledgements

The authors are grateful to the following individuals for providing support, advice, and external review on the report: Arron Nerbas (Narbas Bros. Angus), David Sauchyn (Prairie Adaptation Research Collaborative, University of Regina), Darrin Qualman (National Farmers' Union), Duncan Morrison (Manitoba Forage and Grasslands Association), Ian McCreary, Mark Muller (Regenerative Agriculture Foundation), Scott McFatridge (Sustainable Prosperity Institute), Sophia Murphy (Institute for Agriculture and Trade Policy), Livia Bizikova, Dimple Roy, Tyler Farrow, and Jo-Ellen Parry (International Institute for Sustainable Development).

Ginni Braich and Kushank Bajaj provided valuable contributions on international trade, politics, economics, and global responses to climate change.

This report was made possible through the generous support of the Ivey Foundation.

Executive Summary

The summer of 2021 was not kind to agricultural producers on the Canadian Prairies. While drought is a regular occurrence on the Prairies, the 2021 heat wave, accompanied by a weakened jet stream, shattered records. It challenged the idea that climate change will only benefit Canadian Prairie producers; heat, drought, floods, and severe storms are also part of the predictable picture.

But Canada's agricultural producers have a complicated relationship with climate change that goes beyond simply feeling impacts or adapting to them. The way we farm has impacts that are large-scale enough to matter in Canada's broader greenhouse gas (GHG) emission profile, for better or worse.

This report is about finding solutions that hit the "sweet spot": they reduce Prairie producers' vulnerability to climate impacts, increasing their resilience and viability, while also allowing them to contribute meaningfully to Canada's overall efforts to mitigate climate change.

Canadian Prairie Agriculture: Where are we, and how did we get here?

Coming to terms with the present demands that we understand our past. Prairie agriculture was practiced well before the settlers arrived, but the treaties signed between 1870 and 1920 were designed to replace Indigenous semi-nomadic land management for cultivation and hunting with a European-style agricultural economy based on exporting wheat to Europe.

Newly arrived settler farmers tilled and turned the centuries-old soil for the first time, using methods more suitable for wetter areas, leaving them vulnerable to the drought and wind conditions of the catastrophic dust bowl years in the 1930s. Those desperate years saw the farmers that remained self-organizing, and establishing collective marketing and advocacy tools, including wheat pools and farmers' unions.

Government support eventually came in 1935 in the form of the Canadian Wheat Board—a sole-buyer marketing and market support agency. That same year saw the establishment of the Prairie Farm Rehabilitation Agency (PFRA), which helped farmers adopt farming methods better suited to the Canadian Prairies.

The last 80 years have seen the evolution of prairie farming from a more cooperative model to an industrial effort focused on maximizing agri-food production and exports. Government support in the form of on-farm extension services and supporting research has dwindled, replaced mainly by advice from commercial vendors of farm inputs.

The typical modern Prairie farm is caught in the cross-currents of multiple fundamental changes. The number of farms continues to decline dramatically, while the average farm size has more than tripled since 1970. Acreage under production has also increased with the conversion of rangeland, wetlands, and shelterbelts to cropland. Nitrogen fertilizer use per hectare has increased around three-fold since the 1980s, and pesticide use has more than doubled in the past two decades.

While farm receipts have been rising, in many types of operations, they have been matched or overtaken by the rising costs of inputs, land, machinery and other expenses, and almost half of Canadian farm operators supplement their farm income with off-farm work. The average producer has been getting older, aging from 48 in 1991 to 55 in 2016. Many new producers do not own their land, and there is a trend toward investor-owned land.

Climate change is another encroaching fundamental change. If farm operators are to be fully engaged and prepared as a part of climate change solutions, policy-makers will have to start from a place of understanding the pressures of the present and the history that has led us here.

Climate Change and Agriculture: Adapting to uncertainty

The world has cycled through ice ages and warm periods for millions of years, but our current speed of warming is much faster than what we have experienced historically, and climate change at that speed is disruptive. It is not just a matter of getting warmer; traditional growing seasons and weather patterns will change, disrupting our established ways of life, including how we produce our food.

The Prairies face a number of critical risks that, if unaddressed, could jeopardize agricultural productivity and producer livelihoods. In Canada, the Prairies are warming more quickly than any other region outside of the Arctic. We can expect longer growing seasons and an increased extent of arable land moving north as a result.

Overall, precipitation will increase but will come mainly in the winter and spring—when wet fields impede planting—and will give way to drier summers and falls. Summer precipitation will be increasingly likely to come in intense storm events that lead to overland flooding, contributing to erosion and loss of soil fertility. Heat waves and droughts in the summer will become more common, as will the risk of wildfires. This will create a risk of heat stress for many crops (such as canola, particularly at crucial plant germination stages) and livestock. Warmer winters will mean increased overwintering and northward shifts in pests and diseases such as cereal rusts, striped flea beetles, crucifer flea beetles, deer ticks, and biting midges.

Prairie producers may also be affected by the impacts of climate change policies in export markets. For example, the European Union's proposed "Farm-to-Fork" policies would require the certification of sustainable and ethical practices in crop and livestock production and processing and significant improvements in chain-of-custody regulations.

A final type of impact relates to the changing behaviour of consumers in response to climate change concerns. As one example, we are seeing a small but rapidly growing demand for protein alternatives to meat (driven by concerns for both animal welfare and climate impacts), which could represent an opportunity for pulse growers but a threat to producers of livestock, especially beef.

Prairie producers are resilient and are already taking adaptive actions such as moving to no-till and precision agriculture, changing seeding dates and cropping regimes, using drought- and heat-tolerant varieties, moving to mixed farming, and using crop insurance and climate data for farm planning and risk assessment. Many of these practices not only boost resilience but they also have better environmental outcomes.

But challenges remain. Coping with disruptive change is not just a farm-level effort. Communities and social networks are important elements of resilience, and a smaller, older, more dispersed population with financial stresses means that the community vulnerability of rural and farming communities on the Canadian Prairies is relatively high. Individual producers and communities need to be supported by the right policies, institutions, and infrastructure, informed by local knowledge and an understanding of local realities.

The Impacts of Prairie Agriculture on Climate Change

Any major economic activity produces GHGs, and agriculture is no exception. Producing the food that sustains us is one of the most significant human undertakings, and its impacts are on par with its scale. Agricultural GHG emissions in Canada are 12% of the national total.

Of Prairie GHG emissions, approximately:

- **20% is from on-farm fuel use** (mainly carbon dioxide from farm vehicle combustion and fuel use in grain drying).
- **35% is from crop production** (mainly nitrous oxide from synthetic nitrogen fertilizer use and production, and carbon dioxide, both from energy used to produce fertilizer and other chemicals, and from generating electricity for farm use).
- **45% is from animal production** (primarily methane, mostly from cattle digesting grass, and both methane and nitrous oxide from manure management).

Emissions vary across different operations and regions, but on average, canola has almost twice the GHG emissions per kg of dry matter as spring wheat, which is twice again as GHG intense as tame hay. Enteric fermentation in beef and dairy cattle (digestion gas) accounts for 88% of Canada-wide agricultural methane emissions, with all livestock manure management accounting for the rest.

We know how to reduce these emissions through so-called beneficial management practices (BMPs). Indeed, many producers have already taken steps to improve efficiency and reduce emissions on their farms, both because they see a payback and because they are innovators and stewards of the land. No-till has been widely adopted, precision agriculture and “4R stewardship” practices reduce nitrogen fertilizer use, and methane emissions from cattle have dropped since

2005 due to changes in feed. But many BMPs need policy and industry support in order to make them economically viable for producers.

Canadian Agricultural and Climate Change Policy

Government policy plays an important role in supporting farm-level changes to increase resilience and reduce emissions in the ways discussed above. There is an extensive web of relevant federal and provincial programming, but it bears noting that three fundamental barriers hamstring effective Canadian policy in this space:

- There is no concrete national target for emissions reductions across the entire sector, either at the provincial or federal level. Other countries have such high-level policy signals, providing clarity for producers, communities, and industry on where the agricultural sector must go.
- There is a lack of comprehensive planning and or a strategy on agriculture and climate change across federal government departments and between different levels of government. Best global practice includes comprehensive strategies to achieve their targets for emissions reductions, areas of land under sustainable production, and livelihood goals rather than one-off programs.
- There is a lack of program evaluation and transparency on environmental indicators and low funding availability, meaning we know far too little about the efficacy of current agri-environmental programming.

Agricultural policy in Canada is an area of shared jurisdiction between the federal government and the provinces, which poses significant challenges to ensuring comprehensive climate-compatible policies and programs. Most federal funds to the agriculture sector flow through the Canadian Agricultural Partnership, which has a budget of CAD 3 billion over 5 years ending in 2023. It includes federally funded programs, cost-shared programs delivered by provinces, and a suite of business risk management programs.

Federal agricultural policy has only recently begun to fully mainstream climate change considerations, and even now, the emphasis on resiliency and sustainability in Agriculture and Agri-Food Canada programming is in the context of increasing growth and exports. There still exists a basic tension between Canada's national and international commitments on biodiversity, climate change, and sustainable food practices—most of which are as yet unmet—and its focus on increasing conventional agricultural production and exports.

Canada's updated 2020 federal climate plan includes a target to reduce fertilizer use, sizable budget commitments for such things such as clean agricultural technology, and support for improved nitrogen management, cover cropping, and rotational grazing. Consultations are underway on a federal offset program for large emitters that might include agricultural offsets. Several adaptation and resiliency-focused programs outside of Agriculture and Agri-Food Canada benefit rural communities and producers. However, much more is needed.

No Prairie province has identified emissions reduction targets at the provincial level, and in general, Prairie governments have not targeted the agricultural sector for emissions reductions. While programs to incentivize more sustainable and resilient practices exist, they are limited in scope and accessibility. Each province has some examples of positive and effective programming to promote climate-resilient practices, but overall, climate change mitigation and adaptation have not been fully mainstreamed across agricultural policies and programs. A significant challenge for producers on the Prairies is the general lack of public extension services, especially those that support climate resilience.

A number of innovative initiatives to address climate change impacts and opportunities in agriculture have emerged at the community level, including the Alternative Land Use Service (ALUS), which pays producers directly for eligible nature-based solutions. Another—the Saskatchewan Soil Conservation Association—is a producer-based organization that supports the uptake of new practices and technologies and that played a key role in promoting and facilitating the adoption of low-till agriculture in the province.

Conclusions and Recommendations

Key findings of our research include:

- Emissions from Prairie agriculture are significant and increasing, despite the adoption of BMPs such as no-till by many producers.
- Climate change-related impacts are intensifying, increasing vulnerability and risk for Prairie producers on a number of fronts, including droughts, floods, heat waves, wildfires, increased storm intensity, and migration of pests and diseases.
- Current public support and investment to address sectoral emissions are insufficient.
- The lack of sectoral targets means there is no predictable base for transformative investment in the sector.
- Ensuring lasting change will require a shift in the culture of agriculture. By working with producers, farm communities, and all levels of government and across departments, policy-makers can help ensure that climate action becomes part of the culture of agriculture.

We identify a number of on-farm practices that would increase the resilience and long-term viability of farming operations while also producing environmental benefits:

- Reduced use of nitrogen fertilizer, following “4R Stewardship” principles, and planting of pulses and other legumes.
- Better crop rotations, including the use of perennial crops, cover cropping, and intercropping.
- Rotational and mob grazing to improve pastures.
- Use of crop and livestock rotations.

- Improved livestock practices, including manure management, but also feed practices and strategies to maximize herd health while reducing enteric fermentation.
- Lower operational energy-related carbon footprints, including fuel management, fuel switching, energy efficiency, and renewable energy generation.
- Improved land stewardship practices, including shelterbelts and conservation of forests and wetlands.
- Integrated management of soil, water, and land to deliver increased resilience, more biodiversity (including healthy soils), and climate mitigation.
- Adaptation actions, such as improving on-farm infrastructure, changing planting practices, strengthening water management, practising mixed farming, and using climate data in planning.

Many beneficial farm-level and broader changes can be framed under an agroecology approach, applying ecological principles to enable sustainable food systems. Some of these practices, like 4R (right source, right rate, right time, right place) stewardship, have quick paybacks because of input cost savings. Others, like more efficient equipment, may pay off over time but are significant upfront investments. Others, like manure biodigestion and changes in feed, may have little prospect of paybacks. In general, producers need financial and technical support to adopt these sorts of practices and create systemic change. Drawing on our research and the recent work of others, we identify several types of support as playing that role. Governments can:

- Reinstate funding for public extension services and research with a renewed focus on agroecological practices and climate resilience.
- Introduce crop insurance discounts for BMPs to draw clear linkages between improved practices and reduced climate risk.
- Establish incentives for improved livestock practices, including grazing BMPs, manure management, and the reduction of enteric fermentation.
- Facilitate payment for ecosystem services and nature-based solutions.
- Improve and establish programs to support greening on-farm energy use.
- Ensure robust criteria and processes for agricultural carbon offsets.
- Identify and phase out harmful agricultural subsidies.
- Ensure financial, social, and environmental conditionalities in funding programs.

Industry can:

- Innovate for increased fuel efficiency and zero-emission farm equipment, as well as for feed supplements to reduce digestive methane, and crop development and equipment for techniques like intercropping.
- Support research and market development for sustainable food production.
- Set ambitious corporate targets and roadmaps for emissions reductions and sustainability.

Non-governmental organizations and producer associations can:

- Scale up existing local and regional programs to compensate innovative and climate-resilient producers for their leadership as trainers and mentors on BMPs in their communities.
- Provide research and advocacy for policies that support producers in sustainable transitions.

Partnerships with Indigenous communities to share Traditional Knowledge in support of climate change mitigation and adaptation planning can result in:

- Land trusts, conservation, and the rehabilitation of farmland and pastures, including pasture management of former PFRA lands.
- On-reserve gardening and small-scale farming that involve working with communities to build skills, knowledge, and economic opportunities.
- Land Back efforts with individual farmers and communities.

Finally, the ongoing work to develop the Food Policy for Canada should incorporate climate change as a focus. Comprehensive measures within and alongside the FPC are required to transform agriculture on the Prairies and across Canada, including by:

- Adapting business risk management, the Canada Agricultural Partnership, and the next agricultural policy framework in 2023 to fully integrate environmental issues, build agroecology in Canada, and incentivize best practices.
- Ensuring domestic food and agricultural policies align with international commitments on climate change and sustainability, including through target setting and reporting on progress.
- Improving monitoring and evaluation of federal agricultural programs and supports.
- Ensuring adequate and ongoing consultation with relevant stakeholders, including public consultations.
- Implementing and adequately funding the proposed National Adaptation Strategy in a way that supports producers and surrounding communities.
- Empowering regional networks and local planning authorities to develop local solutions.
- Developing a pan-Canadian soil health strategy.
- Integrating and foregrounding equity, diversity, and inclusion policies and programs to reduce barriers to entry in agriculture.

As Canada moves into an uncertain climate future, rethinking agriculture on the Prairies may require some significant imagination, but this also provides us with an opportunity to go in entirely new directions. Working with multiple stakeholders and Canadian communities, as well as Prairie producers, will allow for a new, more sustainable vision of Prairie farming to emerge.

Table of Contents

List of Figures

List of Tables

List of Boxes

Abbreviations and Acronyms

AAFC	Agriculture and Agri-Food Canada
AB	Alberta
ALUS	Alternative Land Use Services
BC	British Columbia
BMP	beneficial management practice
BRM	business risk management
CAP	Canada Agricultural Partnership
CBD	Convention on Biological Diversity
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DM	dry matter
ECCC	Environment and Climate Change Canada
EFP	Environmental Farm Plan
EGS	ecological goods and services
EU	European Union
F2F	Farm to Fork Strategy
FAO	Food and Agriculture Organization of the United Nations
FRWIP	Farm and Ranch Water Infrastructure Program
FSP	Farm Stewardship Program
GBC	Green Budget Coalition
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
MB	Manitoba
OAG	Office of the Auditor General
OECD	Organisation for Economic Co-operation and Development
PFRA	Prairie Farm Rehabilitation Administration
RCP	Representative Concentration Pathway
SK	Saskatchewan
SSCA	Saskatchewan Soil Conservation Association
UNFCCC	United Nations Framework Convention on Climate Change

1.0 Introduction

The summer of 2021 was not kind to agricultural producers on the Canadian Prairies. Severe drought conditions across much of the southern plains have meant widespread crop failure for farmers, and shortages of feed have been catastrophic for many ranchers, in some cases forcing them to sell their stock (Nickel, 2021; Rosen, 2021). This played out against the backdrop of ongoing wildfires that plagued areas across Canada with smoke for much of the season (Isai, 2021). Conditions for farming in Alberta, Saskatchewan, and Manitoba have posed economic challenges for farmers, but also health and social challenges as farming families and communities have struggled to cope with the stress.

Drought is a regular occurrence on the Prairies, with events expected every 20–30 years. But the heat wave that gave rise to this event, accompanied by a weakened jet stream, shattered records across Western Canada, playing out a script foretold by climate scientists who warn that such events will become increasingly frequent. The 2021 season is a rebuttal to the idea that climate change will only benefit Canadian Prairie producers; along with heat and drought, floods and severe storms are also part of the predictable picture.

Canada's agricultural producers have a complicated relationship with climate change that goes beyond simply feeling impacts. The way we farm—for example, the type of tillage, the application of fertilizer, the management of manure—has impacts that are large-scale enough to matter in Canada's broader greenhouse gas (GHG) emission profile, for better or worse. The Prairie provinces are home to 80% of Canadian agricultural land; they are the "breadbasket" of the country, a major contributor to international food exports, and a source of emissions. The agricultural sector, like other economic sectors, faces a challenge to reduce these emissions to ensure a climate-safe future.

This report is about finding solutions that hit the "sweet spot": they reduce Prairie producers' vulnerability to climate impacts and increase their resilience and viability while allowing them to contribute meaningfully to Canada's overall efforts to mitigate climate change. This is the first of a two-part series that examines the interactions between agriculture and climate change on the Canadian Prairies.

This first report asks how Prairie agriculture and climate change are related. We start by looking at the ways climate change will affect, and is affecting, Prairie producers. Section 2 provides a "long view" of the history of agriculture on the Canadian Prairies with an emphasis on the policy and economic changes that took place from colonization and early settlement, to increasing industrialization, to today's modern farming. That context allows us to better assess where we are today and where we need to go. Section 3 then reviews the potential impacts of climate change on agricultural production and rural communities and asks how communities can adapt to these changes.

Section 4 looks at agricultural GHG emissions for Canada and the Prairies, describing the trends and exploring the ways those emissions can be reduced. In Section 5, we describe and assess provincial and federal policies that impact the agricultural sector's ability to address climate change.

The sixth and final section summarizes the report's findings and makes a series of recommendations, building on the preceding analysis and work done by leading environmental and farmer-focused organizations in Canada. The second report in this series will elaborate on these recommendations in more detail to provide concrete pathways for policy change to enable climate action in the Prairie agricultural sector.

Our objective is to enable producers, including farmers and ranchers, to act individually and together, with the support of policy-makers and industry, to mitigate and adapt to climate change on the Prairies. The scale of climate change requires unprecedented action across all of society, and agriculture is no exception. To succeed, shifting toward climate-safe approaches will require ingenuity, proactive planning, proper investment, strong governance, and collaboration. In keeping with the tenets of sustainable development, our vision of success is an environment and an economy that allow the children of today the opportunity to become the prosperous producers of tomorrow.

2.0
Climate Change Within Historical and Socio-Cultural Contexts on the Canadian Prairies

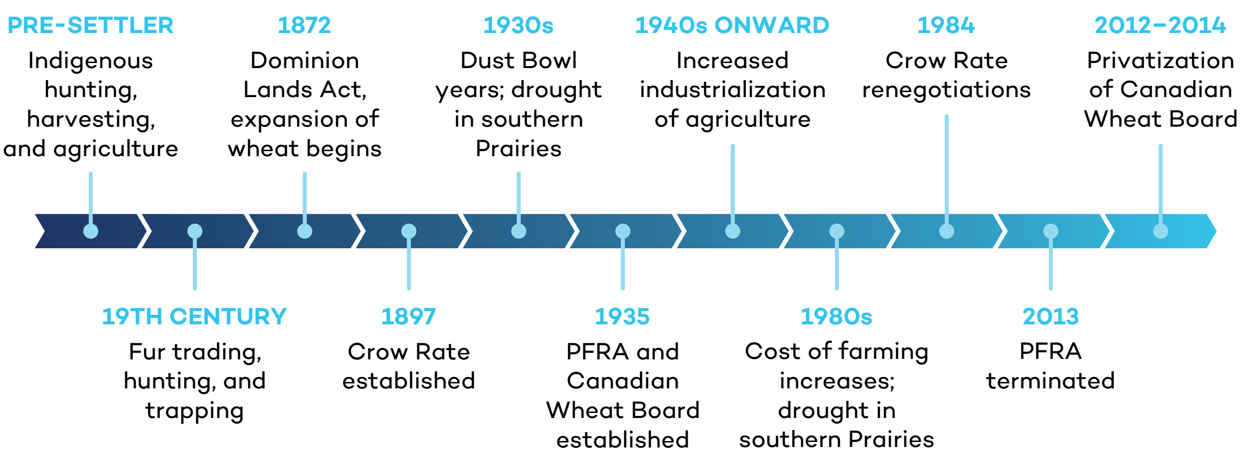
In order to develop effective climate change policies, it is important to understand the current and historical social, economic, and cultural realities of farming communities on the Canadian Prairies. In this section, we briefly survey the history of Prairie agriculture from pre-colonial time to the present. Land use and farming on the Prairies has changed immensely over time, with implications for producers and policy-makers. We examine how food has been produced and harvested, who was involved, and how key organizations, institutions, and government policies have impacted how agriculture on the Prairies was practised. Importantly, the history of settler colonialism and ongoing socio-economic challenges contribute to unique vulnerabilities and adaptive capacity within the Prairie agricultural sector.

While large-scale landscape changes are part of the history and current reality of the Prairies, anthropogenic climate change presents a new and significant threat to Prairie communities and agricultural livelihoods. Previous dramatic landscape changes on the Prairies, as outlined in this chapter, illustrate the risks and socio-economic impacts that occur when environmental change is neither prevented nor properly adapted to.

Key messages:

- Policies to support producers in responding to climate change must build on lessons learned from past agricultural and rural policies and their positive and negative effects on rural populations (for example, the Prairie Farm Rehabilitation Administration [PFRA], farmer collective approaches, etc.).
- Key trends in 21st-century farming include increased farm size (with fewer total farms) and cropland production, increased use of synthetic inputs, with links to ecosystem impacts and climate change.
- There are conflicting policies within governments that make it challenging for producers to act to protect the environment.

Figure 1. Key events in the history of Prairie agriculture



2.1 Historic Land-Use Change

Prairie landscapes were once home to vast amounts of biodiverse native grasslands, with millions of bison (a keystone species). Bison and grasslands had evolved together for centuries before the fur trade began. Healthy grasslands and soils relied on the heavy but temporary browsing of roaming bison herds and the trampling of their hooves (Savage, 2004).

Indigenous Peoples subtly changed the Prairie landscape before European exploration or settlement.[1] Most followed a primarily hunting way of life, alongside low-impact plant cultivation, or agriculture, though it was not acknowledged as such because it did not resemble European agriculture (Carter, 2016; Daschuk, 2013; Herriot, 2016). Indigenous communities were primarily nomadic but visited the same territories at the same time each year, making it possible to encourage and cultivate plants, including berries, root vegetables, and wetland plants, through management processes that included controlled fires, digging, and sowing of "wild" seeds (Davidson-Hunt, 2003, Massie, 2014).

In one of the first human-caused landscape transformations in the region, European fur traders and First Nations and Métis hunters and trappers impacted the landscape through the overharvesting of bison and beaver in the 19th century. Overharvesting of bison and the intentional slaughtering by officials in both Canada and the United States eventually led to the decimation of bison populations (Olson, 2019), alongside devastating impacts to Indigenous communities, and marked the start of a longer transition from native grasslands to cultivated agriculture in much of the Prairies.

2.2 Historic Farming Communities and Their Responses to Environmental Change

The land on the Prairies is completely covered by numbered treaties. In the late 19th century, settler farmers began to establish themselves across the Canadian Prairies. Seven treaties were negotiated in the region between 1871 and 1921 (Epp, 2008; Russell, 2012). From the perspective of the Canadian government, the treaties enabled the building of a railroad to facilitate the arrival of settlers and the establishment of agricultural production, particularly for exporting wheat to Europe (Russell, 2012). The federal government's Dominion Lands Act of 1872 sold a quarter section of land for CAD 10 to those who could plow the land and live there as part of the government's effort to establish a wheat export economy (Yarhi & Regehr, 2020). Tensions of land rights, access, and ownership have modern-day implications and should be considered as governments develop agricultural climate change policies, particularly for linkages with reconciliation with Indigenous Peoples.

[1] These include the Siksika, Piikani, Kainai, Dakota, îyârhe Nakodabi (also known as Stoney Nakoda), Nehiyawak (also known as Cree), Nakoda Oyadebi (also known as Assiniboine), Tsuut'ina, Ojibway, and Dene (Brasser, 2019).

While periodic droughts had been well documented by early explorers, including in southern Saskatchewan and Alberta, where the land was deemed unsuitable for agriculture (Palliser's Triangle), the federal government ignored these warnings in an effort to assert dominion over the territory through settlement (Potyondi, 1995). Newly arrived settler farmers were tilling and turning the centuries-old soil for the first time and using methods more suitable for wetter areas. In the 1930s, they were hit hard by the lack of rain and by prevailing winds that blew away valuable topsoil in "black blizzards" that reached as far as eastern Canada (Cunfer, 2005; Owram, 1980). Many farmers did not stay and instead returned to Europe or moved to urban centres; those that did stay migrated northward where conditions were more favourable (Massie, 2014). The Dust Bowl years were a catastrophe in every sense—economic, environmental, and social—and they continue to serve as a warning to both farmers and policy-makers on the Prairies today.

As a result of the lack of government support, some farmers in the 1920s and 1930s took the initiative to self-organize and establish collective marketing and advocacy tools, including wheat pools and farmers' unions, with some branching out to establish supporting infrastructure like local banks and telephone lines (Atkinson & McCrorie, 2003). These strategies helped farmers by establishing better prices and living conditions but also strengthened broader social supports and communities (Eaton, 2013; Magnan, 2011). Cooperative tendencies dominated the Prairies until the 1970s and 1980s and helped establish many farmer-led institutions (Eaton, 2013; Magnan, 2011; Skogstad, 1987).

The Crow Rate, or the Crowsnest Pass Agreement of 1897, saw the Canadian government pay the Canadian Pacific Railway a cash subsidy and title to the mountain pass in British Columbia (BC) in exchange for reducing, in perpetuity, eastbound rates on grain and flour (Norrie & Regehr, 2014). While it was unsustainable in the long run, the Crow Rate was a concrete policy expression of support for Prairie farmers at a time when few others existed, leading to an increase in farm settlement (Norrie & Regehr, 2014).

As the Great Depression lingered, the federal government established several welfare policies, including so-called "make work" projects, like the construction of dams to control water supplies. In 1935, the Canadian Wheat Board was established, which acted as a marketing agency on behalf of grain producers and eventually became the sole seller and buyer of select Prairie grains, including wheat. That same year, the federal government also established the PFRA to help Prairie farmers adapt to natural resource constraints (including drought) and shift European agricultural approaches to farming practices that would work in the Prairie context (Marchildon, 2009). The PFRA was a branch of the federal agriculture department and supported farmers in the conservation of soils, the development of water resources, and the management of community pastures. The PFRA also conducted extensive surveys of soils and hydrological conditions and research on cultivation practices (Marchildon et al., 2008).

The PFRA was extremely successful in changing farming practices (Marchildon et al., 2008). For example, one successful program distributed free trees to help farmers establish shelterbelts to protect farmland from wind erosion while also supporting biodiversity and preventing localized flooding. There is also evidence that the tree-planting program helped lessen the impacts of wind erosion from subsequent droughts in the 1980s and early 2000s (Marchildon et al., 2008). Millions of trees were planted by the program's end in 2013 (Amichev et al., 2015). The PFRA also changed farming practices by ensuring that farmers knew how to manage water systems on their farms, including building dugouts for livestock and growing crops around seasonal sloughs (Marchildon. 2009). Even before the program was terminated in 2013, attitudes and behaviours around farming practices were changing (Arbuthnott & Schmutz, 2013).

2.3 The Modern Farming Sector and the Transition to Conventional Production

Conventional agricultural production in Canada has become increasingly industrialized since the 1940s, with a focus on maximizing agri-food production and exports. This transition has been supported through both government policies and private interests, including the privatization of the Canadian Wheat Board and the ending of the PFRA in the early 2010s. The transition has meant larger farms with fewer farmers and farm workers or animal power, bigger farm equipment, and increased synthetic input use (Isaac et al., 2018).

Transportation by rail of grains and oilseeds continues to dominate Prairie agriculture, but it also continues to present a challenge to farmers, rail line companies, and governments. In 1983–1984, the federal government renegotiated the Crow Rate with the Canadian Pacific Railway, and farmers began to pay more to move their products to international markets via BC (Beingessner, 2003). Farmers were now being charged to maintain all rail lines, including smaller branch lines, which contributed to tensions between farmers in the "hinterlands" and those along main lines (Beingessner, 2003).

The 1980s and 1990s were dominated by the ideology that less government is better. In agriculture, this meant a reduced role for government and increased cost of business for many farmers (Atkinson & McCrorie, 2003; Eaton, 2013; Magnan 2011). This paradigm also involved a shift wherein farmers identified themselves less as environmental stewards supporting the common good, or members of collective and farmer-led organizations for economic equality, and more as individual actors with increased pressure to stay afloat (Burton, 2004; Kuyek 2007; Lind, 2003). Extension services and public research in Canada were publicly funded by governments and universities well into the 1980s (Ontario Centre for Climate Impacts and Adaptation Resources, 2017). Universities and provincial governments cut funding to public research on crops and on-farm practices in the 1990s and 2000s (Milburn et al., 2010; Tarnoczi & Berkes, 2010). The PFRA was eventually terminated in 2013. Public extension services have been reduced and shifted toward more passive and less personalized forms of assistance than field staff, such as online information sources (Milburn et al., 2010). Private corporations have also filled the gap (Kneen, 1990; Kuyek, 2007), and their advice has tended to direct farmers to use more of the seeds, fertilizers, and other inputs they happened to be selling (Eaton, 2013). Many farmers have begun to access information from multiple sources, including private sector advisors (Fawcett-Atkinson, 2020a; Ontario Centre for Climate Impacts and Adaptation Resources, 2017).

These trends, and the advent of new technologies, resulted in many changes to the Prairie landscape as many farmers made changes to maximize cropland. Equipped with larger machinery and able to farm more land, farmers removed shelterbelts to enlarge their fields since the advent of no-till and direct seeding meant they no longer worried about soil erosion (Argue et al., 2003). Many also installed drainage systems on their land to drain wetlands.

When a prolonged drought arrived in the 1980s, combined with high interest rates and increased farm debt, a 1930s-style mass exodus of farmers happened again (Sommerville & Magnan 2015). The loss and privatization of farmer-led institutions, including the Canadian Wheat Board in the mid-2010s, further entrenched approaches that saw farmers as better off seeking free-market opportunities than acting collectively (Magnan, 2011). This increase in competition also resulted in the failure of some farms and contributed to a transition to investor-owned farmland (Desmarais et al., 2017). Saskatchewan, for example, saw a 16-fold increase in land owned by investors from 2002 to 2014 (though this is still less than 2% of total land under cultivation) (Desmarais et al., 2017).

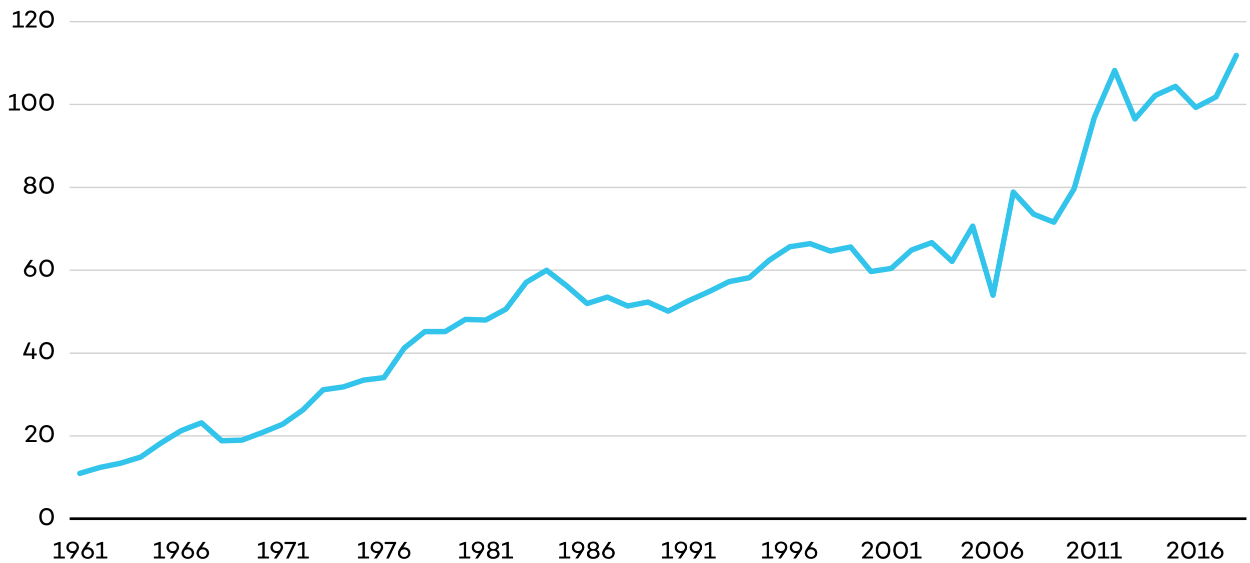
2.4 Prairie Farming in the 21st Century and Implications for Climate Change

Today, the Prairie provinces are home to approximately 17% of Canada's population (Statistics Canada, 2017a), with a higher-than-average rural population. In addition, 39.2% of Canada's Indigenous population lives in the region.

Trends in Prairie farming in the 21st century illustrate the cumulative impacts of the past decades of economic and environmental policies and subsequent landscape changes. This includes the move toward high-input agriculture, the use of which often represents high costs for farmers. On Canadian farms, nitrogen fertilizer has increased around three-fold since the 1980s, and pesticide use has more than doubled in the past two decades (Figures 2 and 3) (Food and Agriculture Organization of the United Nations [FAO], n.d.; Qualman, 2019; World Bank, n.d.).

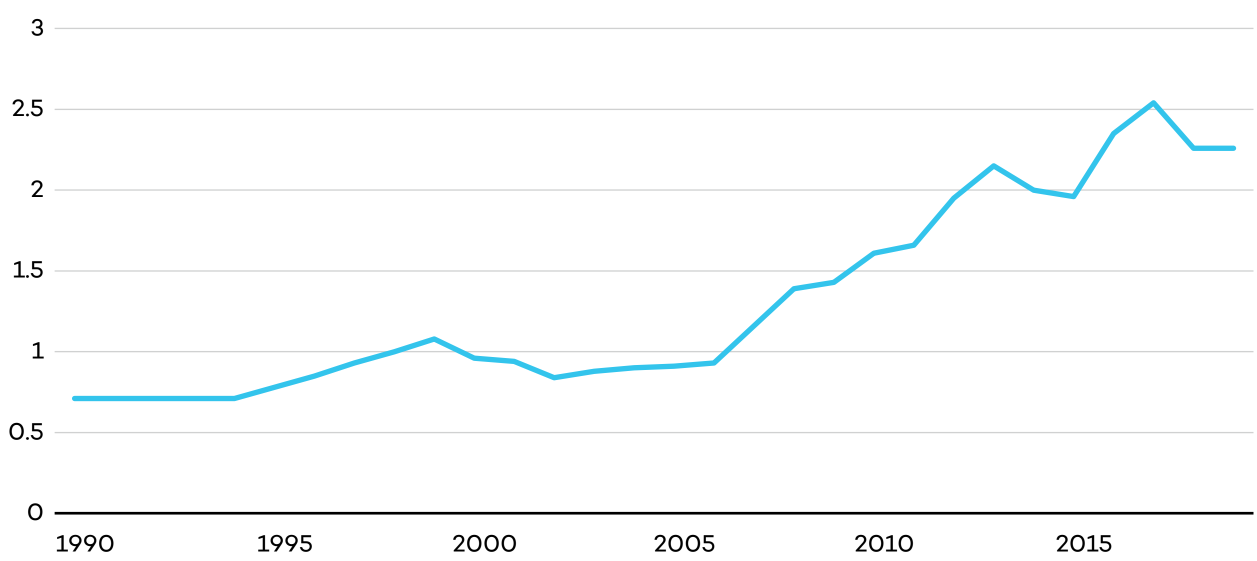
Currently, agricultural policy in Canada is dictated heavily by provincial policies and the Canada Agricultural Partnership (CAP). Negotiated between the federal and provincial governments, the CAP includes a variety of funding programs. Federal approaches, including the CAP, have helped to orient the sector toward exports and have been criticized for overemphasizing growth and technology without adequately considering sustainability implications (Wilson, 2017). We explore these dynamics further in Section 5.

Figure 2. Fertilizer consumption in Canada over time (kg per hectare of arable land)



Source: Data from World Bank, n.d.

Figure 3. Pesticide use in Canada over time (kg per hectare of arable land)



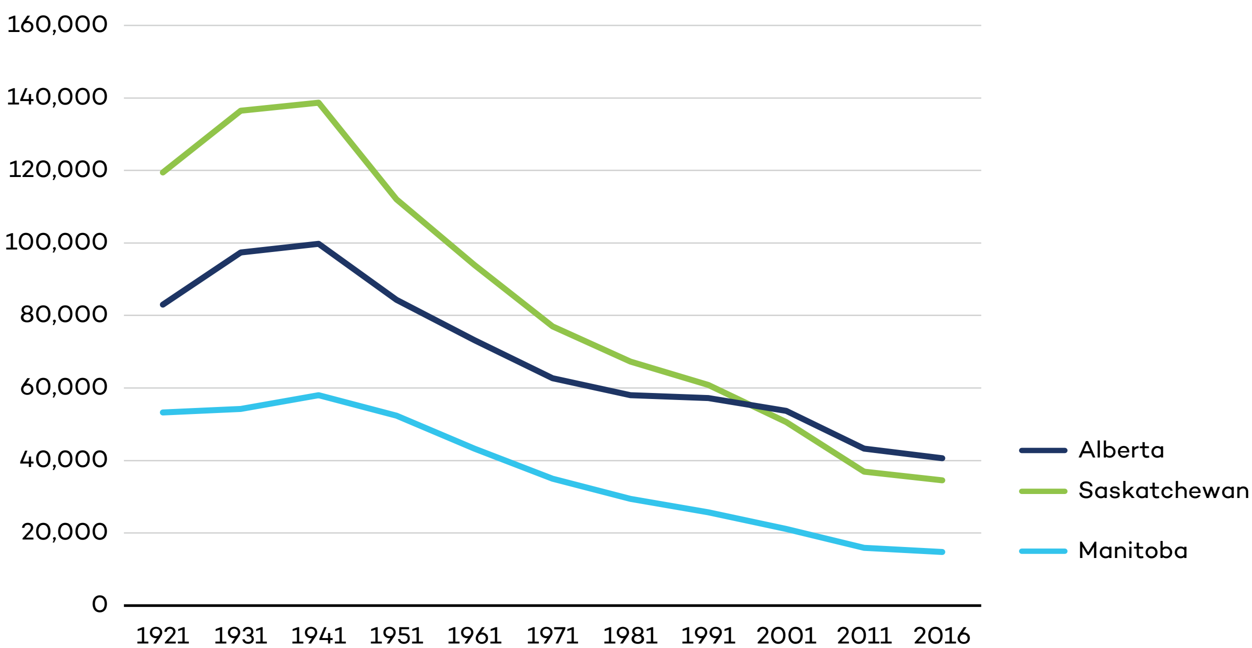
Source: Data from FAO, n.d.

2.4.1 Decrease in Total Number of Farms

The portrait of the average Prairie farm as a small, family-run operation with one or more commodities is changing. While many farms are still individual or family run, the number of corporate farms is growing. In 1971, 97.6% of Canadian farms were categorized as sole proprietorships or partnerships, and 2.2% were corporations (family or non-family) (Statistics Canada, 2017b). By 2016, the percent of incorporated farms increased to 25.1%. Corporations may offer business and legal advantages as the size and complexity of a farm grows. These corporate farms are still operated by families, with 22.5% reporting as family corporations compared with 2.7% as non-family corporations in 2016 (Statistics Canada, 2017b).

The number of farms across Canada has decreased dramatically over the past 80 years, from over 730,000 farms to an all-time low of 193,492 farms in 2016. That year, there were 14,791 farms in Manitoba, 34,523 farms in Saskatchewan, and 40,638 farms in Alberta (Statistics Canada, 2017d) (see Figure 4).

Figure 4. Number of farms in Prairie provinces, 1921–2016



Source: Data from Statistics Canada, 2017e

2.4.2 Increase in Farm Size, Agricultural Land Use, and Crop Production

Farm size on the Prairies is considerably larger than the rest of Canada and massive when compared to the average farm size in European countries. In 2016, the average farm on the Prairies was 1,404 acres, compared to 820 acres for Canada (Statistics Canada, 2017b). In 1971, the average Canadian farm size was only 463 acres (Statistics Canada, 2017b).

Farmers are now farming more cropland than ever before, particularly as more farmers have converted pastures from livestock production to cropland (Statistics Canada, 2017b). The expansion of agricultural land has significant implications for the ability of ecosystems to sequester carbon and maintain biodiversity. Native grasslands in Canada are at a small fraction of their original state and continue to decline on the Prairies, while wetlands continue to be converted for agriculture (Office of the Auditor General, 2018). Most agricultural lands in Canada have low capacity to support wildlife habitat (Office of the Auditor General, 2018).

2.4.3 Trends in Production

Current Prairie agriculture is somewhat diverse, with warm-weather crops such as corn and soy grown in southern portions of Manitoba, more forage crops in the Peace River areas of Alberta's north, and diverse animal operations throughout the provinces. Around 46% of Prairie farms are producing oilseeds and grains, in part due to the higher amount of arable land available on the Prairies (Statistics Canada, 2017b, 2017c). The three main crops produced on the Prairies are wheat, canola, and forage crops (especially alfalfa), with lentils coming in a close fourth (Statistics Canada, 2017d). The three main livestock animals are cattle, horses, and chickens (Statistics Canada, 2017d). The Prairie provinces are responsible for just over 80% of the total beef cattle in Canada (Statistics Canada, 2017d).

From 2011 to 2016, the area of land seeded using no-till technology increased by 16.8% to 48.2 million acres (Statistics Canada, 2017b). This has resulted in a rapid decrease in the use of summer fallow, with areas using summer fallow down by 57.1% since 2011 (Statistics Canada, 2017b). At the same time, the area of hay and alfalfa cropland has declined by 16.6% (-2.8 million acres), while the area of pasture decreased 4.4% (-2.2 million acres). The latter is due in part to a smaller beef herd (beef and feedlot operations declined by 3.7% across Canada from 2011 to 2016) (Statistics Canada, 2017b). Some of the land previously used for hay and pasture has been converted to field crop production (Statistics Canada, 2017c). While the number of pigs has increased in recent years, this was preceded by a significant decline in pork production due to increased costs and lower prices.

Canada and the Prairie provinces rely heavily on both exporting and importing food. For example, Canada exports half our beef, 70% of our soybeans, 70% of our pork, 75% of our wheat, 90% of our canola, and 95% of our pulses (Canadian Agri-Food Trade Alliance, 2017). Our current agricultural system is designed to maximize agricultural production and to export it. For example, lentils are becoming a significant crop in Saskatchewan due to growing demand from international markets (Statistics Canada, 2017c). This reliance on international demand can make farmers vulnerable to international markets and trade relations, as we will discuss later in Section 3.3.

2.4.4 Shifts in Producer Incomes

The 2016 Census of Agriculture found that 44.4% of all farm operators did some off-farm work, usually as a means of supplementing their total income (Statistics Canada, 2017c). While farm revenues have been increasing, the costs of inputs and other farm expenses have also increased, resulting in lower expense-to-receipt ratios (See Table 1). For example, farmers are reporting larger and more expensive equipment as average farm sizes have grown (Statistics Canada, 2017c). Across Canada, the total value of farm machinery and equipment owned and leased by farmers increased between 2011 and 2016 by 15.4%. Gross farm receipts were CAD 69.4 billion in 2015, while operating expenses were CAD 57.5 billion (Statistics Canada, 2017c). The average Canadian farm incurred 83 cents in expenses for every dollar in gross farm receipts in 2015 for an expense-to-receipt ratio of 0.83. This varied by operation type (see Table 1).

Table 1. Operating expense-to-receipt ratio by operation type, Canada, 2010 and 2015

	Expense-to-receipt ratio	
Operation type	**2010**	**2015**
Animal		
Beef	0.93	0.90
Dairy	0.73	0.77
Hog and pig	0.92	0.90
Poultry and egg	0.84	0.84
Sheep and goat	1.01	0.96
Other animal	0.88	0.88
Crop		
Oilseed and grain	0.76	0.79
Vegetable and melon	0.84	0.83
Fruit and tree nut	0.90	0.84
Greenhouse and nursery	0.86	0.85
Other crop	0.89	0.83

Source: Adapted from Statistics Canada, 2017c.

2.4.5 Changes in Producer Demographics

The average age of farmers continues to climb in Canada. On the Prairies, the average farmer in 2016 was 55, compared to 48 in 1991 (Statistics Canada, 2017d). However, there has been a recent increase in the number of farmers under 35 years of age (Statistics Canada, 2017b). Younger farmers are less likely to own the land they farm on, with approximately 50% renting (Statistics Canada, 2017b). They are often renting from farmers over 70, who may be using the additional income to supplement them as they scale back their own operations and transition into retirement (Statistics Canada, 2017b). The number of female farmers has continued to increase since 1971 when the Agriculture Census in Canada first began monitoring this data (before then, it was assumed that farmers were only men) (Leckie, 1993). These trends of increases in young and female farmers may provide an opportunity for climate change policy since these populations have been shown to prioritize environmental issues (Monllor, 2012; Sachs et al., 2016).

2.5 How Do Historical and Socio-Cultural Trends in Prairie Agriculture Intersect With Climate Change?

The changes on Prairie farms and agricultural land over past decades, including increased production and the use of synthetic inputs, have resulted in significant environmental impacts, including dramatic increases in farm-level GHG emissions (we explore this in more detail in Section 6). However, individual farmers are not solely to blame for this increase, since farm-level decision making has come under pressure from systematic changes in economies, societies, and policy and regulatory landscapes. For example, the loss of the Crow Rate increased transportation costs for many farmers and changed the way they made decisions about what to grow and where to farm, with a greater emphasis placed on growing the most profitable crops rather than on healthy crop rotations (Beingessner, 2003). As another example, the loss of public extension services from governments and universities has resulted in private corporations providing recommended application rates for fertilizers and pesticides, rates that may maximize their profits rather than providing opportunities to save farmers money or protect the environment (Kuyek, 2007).

When considering the climate change challenges facing Prairie agriculture, it is important to remember that these issues go beyond the farm level and are part of a broader culture and system of industrialization. For example, the PFRA is often lauded as a policy success since it saw a significant change in farming behaviour and practices on the Prairies and supported farmers in massive efforts to reduce soil erosion and improve water retention on farms (Marchildon, 2009). Many social, economic, and policy changes have taken place since the heyday of the PFRA, so future policy solutions must build on past successes while addressing current realities. There has already been positive momentum in the past 25 years, as collaboration has increased between producers, researchers, and policy-makers to improve climate resilience in the sector (Warren & Lulham, 2021).

Policies that push farmers to change without considering the systemic barriers that challenge farmers to adopt sustainable and climate-friendly farming practices will fail. These barriers include the lack of political power held by farmers and the overwhelming influence of corporations in our agriculture and food systems (Dale 2020; Isaac et al., 2018). In general, corporations benefit from maintaining the status quo since they already have a large market share of inputs, transportation, processing, and retail facilities. Policies must be concerted, holistic, flexible, and based on processes that include farmers and communities themselves. Since new farmers have an advantage when it comes to adopting sustainable practices—as they are less likely to be path dependent (and are therefore more agile when it comes to shifting practices as they are establishing their farms)—policies should also support established farmers.

Further Reading

Atkinson, R. & McCrorie, J. N. (2003). The decline of agrarian radicalism on the Canadian Prairies. In H. P. Diaz, J. Jaffe & R. Sterling (Eds.), *Farm communities at the crossroads: Challenge and resistance* (pp. 323–328). Canadian Plains Research Centre, University of Regina.

Carter, S. (1992). *Lost harvest: Prairie reserve farmers and government policy*. McGill-Queen's University Press.

Daschuk, J. (2013). *Clearing the plains: Disease, politics of starvation, and the loss of Aboriginal life*. University of Regina Press.

Herriot, T. (2016). *Towards a Prairie atonement*. University of Regina Press.

Marchildon, G. P., Kulshreshtha, S., Wheaton, E., & Sauchyn, D. (2008). Drought and institutional adaptation in the Great Plains of Alberta and Saskatchewan, 1914-1939. *Natural Hazards, 45*(3), 391–411. https://doi.org/10.1007/s11069-007-9175-5

3.0
Climate Change and Agriculture: Adapting to uncertainty

This section outlines some of the current and expected impacts of climate change on agriculture on the Prairies and how farm communities and producers can prepare.

Key messages:

- Crop yields and livestock production will be increasingly impacted by climate change, and producers must find ways to minimize risk.
- Climate change will add additional challenges and may exacerbate other environmental challenges, such as biodiversity loss and invasive pests.
- Efforts taken by other countries to reduce emissions and adapt to climate change will impact international markets and prices for Canadian producers. Both climatic changes and the resulting economic shifts will impact how producers run their operations.
- Vulnerability to climate change and the related impacts are a function of individual and collective resilience. Policies that support long-term change on the Prairies are needed to support on-farm practices that increase resilience and establish enabling environments for success. Agroecology is the science, practice, and movement of sustainable food; it is also an opportunity to adapt to climate change and ensure livelihoods for producers.

3.1 Projected Climate Change Impacts on the Prairies

Climatic conditions are the result of complex interactions between the atmosphere, land, water bodies, global circulations, seasonal fluctuations, natural and man-made chemical cycles, and other variables, all of which are entwined with multiple decadal and multi-decadal cycles. Global-scale models are increasingly accurate, providing researchers and policy-makers with an understanding of the changes we can expect as global temperatures continue to rise. It becomes progressively more difficult to model climatic conditions and impacts as the focus gets more localized and as the availability of high-quality regional data remains challenging. For example, it can be difficult to predict the extent to which extreme weather events—including severe storms and tornadoes, increased flood risk, and large wildfires—will increase in a specific community.

Below, we outline some of the changes projected in climate models that producers and communities will need to grapple with as the climate warms. However, variability will also increase as the climate changes, making predicting specific conditions in a given period of time difficult (Bush & Lemmen, 2019). There may also be more rapid swings between wet and dry or hot and cold weather. These inherent uncertainties make it challenging to assess the full extent of direct and indirect impacts to the agricultural sector.

3.1.1 General Warming and Seasonal Shifts

Canada is warming almost twice as fast as the rest of the world, and **the Prairies are warming more quickly than any other Canadian region except the Arctic** (Bush & Lemmen, 2019).

Between 1948 and 2016, average temperatures in the region increased by 1.9°C, and winter temperatures alone went up by 3.1°C (Zhang et al., 2019). How temperatures continue to increase will depend largely on how rapidly Canada and the global community can reduce GHG emissions. Current modelling indicates temperatures on the Prairies will increase by a median of 6.5°C by 2081–2100 under a high-emissions scenario and 1.9°C in a low-emissions scenario, generally compatible with the Paris Agreement (Zhang et al., 2019).

Linked to general warming are fewer cold days in winter and higher maximum temperatures year-round. Daytime and nighttime temperatures are both expected to increase. General warming may also increase mid-winter thaws, which can, in turn, impact the likelihood of flooding. As the climate warms, seasons will shift. Growing season length is expected to increase due to shorter winters and higher overall temperatures (Sauchyn et al., 2020).

General warming and longer growing seasons will force changes in practices such as shifts in seeding dates and harvest times. Increased heat in summer may result in heat stress for many crops, such as canola, particularly at crucial plant germination stages, yet it may expand the range of certain crops such as soybeans (Jing et al., 2017; Sauchyn et al., 2020). Developing new heat- and drought-tolerant cultivars may help producers adapt (Qian et al., 2018).

3.1.2 Changes in Precipitation and Related Risks

As the climate changes, we can expect significant changes in the intensity, frequency, and duration of precipitation in Prairie provinces. High-emissions scenarios are projected to lead to severe moisture deficits, including drought conditions, within the next 30 years across much of the Prairies, causing a strain on the availability of groundwater or river water for irrigation (Warren & Lulham, 2021). Droughts also impact soils through wind erosion, resulting in poor air and water quality. Warmer temperatures will cause a decline in soil moisture levels due to an increase in evaporation and transpiration in soils during growing seasons (Cohen et al., 2019).

This decline may not be offset by precipitation, depending on what season it occurs in. While annual precipitation is expected to increase overall, it is expected to occur mainly in the winter and spring, coming earlier in the year (Sauchyn et al., 2020). Wetter springs will likely give way to drier summers and falls.

Since temperatures are rising, precipitation will be more likely to fall as rain rather than snow (Kulshreshtha, 2019). Reduced snowfall in the winter will mean lower water levels in Prairie wetlands, especially in the south, where these wetlands are already precarious.

At the same time, projections show that individual extreme rainfall events will increase in frequency (Sauchyn et al., 2020). Floods may be increasingly linked to heavy rain or snow (Pomeroy et al., 2015). Extreme rainfall can also have dangerous impacts on water quality, as nutrient runoff can increase (Venema et al., 2010). Overland flooding resulting from either spring runoff or heavy summer rainfall is a high risk for agriculture (Sauchyn et al., 2020), particularly in areas of flat topography with poor natural drainage systems. Floods contribute to soil erosion and the deposition and concentration of sediments, including salts, that can have serious long-term implications for soil fertility.

The upshot is a seemingly paradoxical increase in the risk of both drought and flooding across the Prairies (Sauchyn et al., 2020). Due to the natural variability in precipitation on the Prairies, it will become increasingly common for some areas to suffer droughts and grassland wildfires while others are flooding. Farmers, municipal and provincial governments, and inter-regional organizations have undertaken various strategies to address this increased risk, including proposed irrigation projects, constructing dams and diversions, and improving flood forecasting (see Section 5, for examples).

3.1.3 Extreme Weather Events

While average temperatures and conditions will shift gradually, **extreme weather events will become more likely** and pose a great challenge for producers and communities to deal with, even in the short term. Extreme weather events are already worsening on the Prairies (Sauchyn et al., 2020). Beyond drought and flooding, events such as heat waves, wildfires, and severe summer and winter storms (including hail, wind, or ice storms) will likely increase. Overall warming will lengthen the wildfire season, while hotter and drier conditions increase wildfire fuels, making fires more likely and their spread and burn more intense. According to Sauchyn et al. (2020, p. 19), “almost none of the future scenarios include sufficient increases in precipitation to compensate for the drying effect of warmer temperatures.”

While it is difficult to attribute recent extreme weather events to climate change, the techniques to do so are improving. A preliminary study of the 2021 Pacific Northwest heat waves found the high temperatures (including 49.6°C in Lytton, BC) to be “virtually impossible without human-cause climate change” (Philip et al., 2021). There have been studies showing that natural hazards on the Prairies were exacerbated by climate change, including the 2013 floods in southern Alberta (Pomeroy et al., 2015) and the 2015 drought in Western Canada (Szeto et al., 2016). For the former, increased temperatures in Alberta allowed for higher levels of precipitation to accumulate in the atmosphere, which contributed to intense rainfall (Zhang et al., 2019).

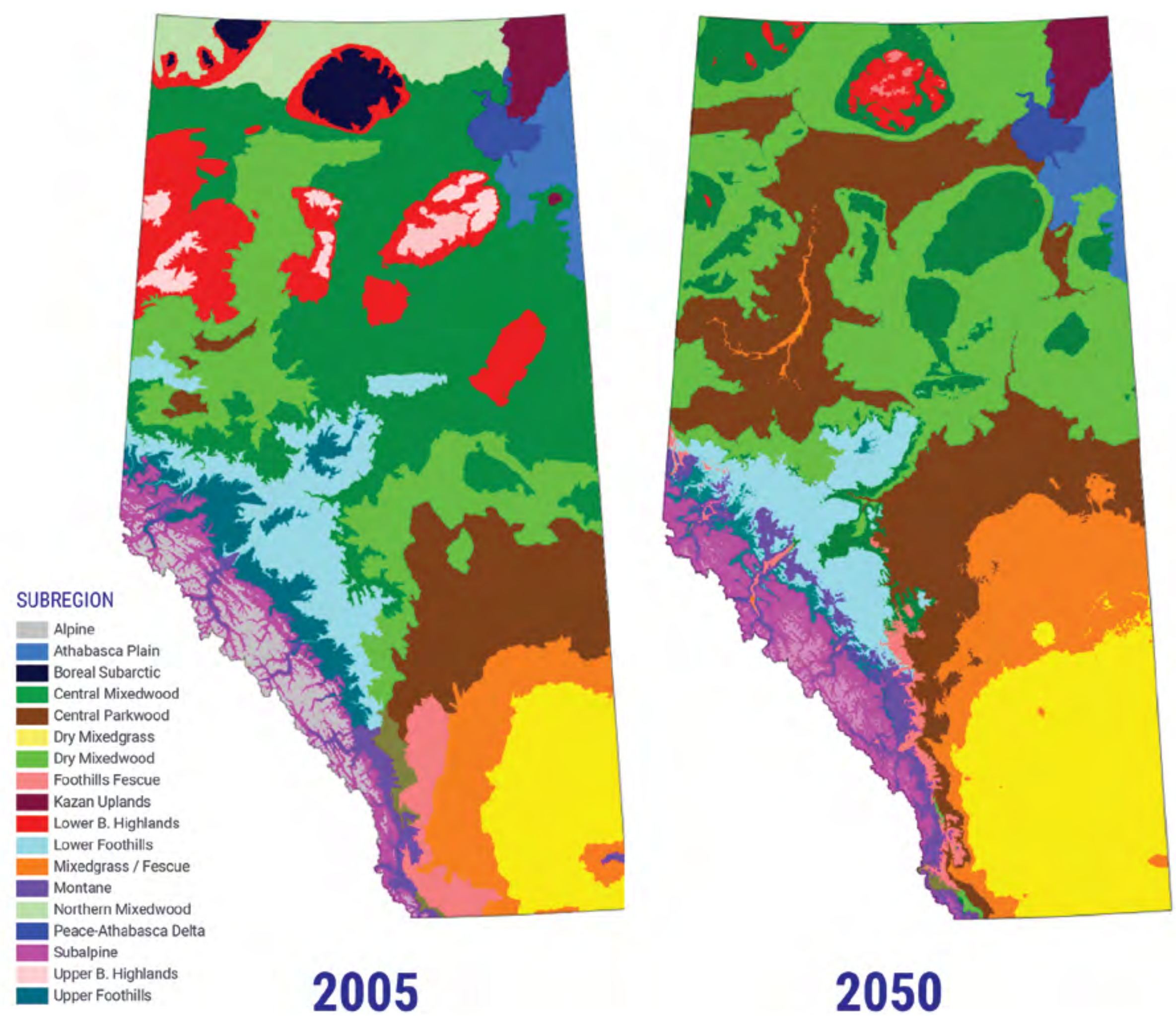
Flooding and extreme weather could also impact grain handling and the transportation network that Prairie producers rely on, and therefore the capacity of producers to ship goods to market (Warren & Lulham, 2021). It may also create significant added costs for producers.

The social and economic impacts of extreme weather impacts can be severe. More than a few consecutive years of drought would be devastating for Prairie producers and communities, as illustrated by historic droughts such as those in the 1930s (see Section 2). The economic impacts from extreme weather events are significant: Canadian Prairie droughts in 2001 and 2002 reduced agricultural production by CAD 2.97 billion (Wheaton et al., 2008), and flooded agricultural lands in 2014 caused CAD 1 billion in damages in 2014 in the southeastern Prairies (Szeto et al., 2014). Social impacts from these events are also severe; we explore human responses and the social dimensions of resiliency in Section 3.5.

3.1.4 Ecosystem Transition

In Canada and the Prairies, climate change will result in ecosystem transitions over time, including a northward shift in the aspen parkland and grassland ecosystems at the expense of the boreal forest. These transitions are likely to be the most significant in Alberta, where many areas are already near a climate transition between forest and grassland (see Figure 5). Since Saskatchewan and Manitoba receive more precipitation than Alberta, they may be less likely to experience dramatic ecosystem transitions. However, ultimately, the extent of ecosystem transition will depend on the rate and pace of climate change.

Figure 5. Ecosystem transitions for Alberta from 2005 to 2050[2]



Source: Sauchyn et al., 2020, adapted from Schneider & Bayne, 2015

[2] Based on a bioclimatic envelope model projection, using a medium emissions scenario (ECHAM5-A2).

The potential to expand agricultural land as the result of ecosystem transition is significant in Canada, with an estimated 4.2 million km^2 available (Hannah et al., 2020). However, expanding agriculture comes with significant risks that will need to be managed. Extending agriculture in northern parts of the Prairies will require adapting farming practices to nutrient-poor forest soils (Sauchyn et al., 2020). As water deficits continue in certain boreal regions, soil quality may become even further diminished (Warren & Lulham, 2021). Converting new land into crop production will also have significant impacts on local ecosystems, such as the potentially significant loss of biodiversity and habitat, which has its own negative impacts on local communities and society at large (Sauchyn et al., 2020).

3.1.5 Impacts on Pollinators and Pests

Along with ecosystem transitions, **there may also be species loss and shifts in ranges of other species** (Pearson et al., 2014). Ecosystem transitions have significant potential to disrupt co-dependent species relationships, which could negatively impact the populations and diversity of pollinators (and subsequently impact the crops that rely on them) (Sauchyn et al., 2020). Changes in precipitation, including longer snow-free periods, may reduce water in wetlands, which will further impact biodiversity, as wetlands are important breeding grounds for waterfowl and other animals and insects (Savage, 2004). Healthy wetlands are important habitats both for pollinators and for natural predators for pests, reducing the need for pesticides; they also contribute to farm-level flood control, nutrient cycling, and ecological services (Lillo et al., 2019). Effective wildlife management and conservation strategies will be vital to ensuring the resilience of Prairie ecosystems and wildlife.

Low temperatures in the winter currently limit the range of pests, vector-borne diseases, and invasive species on the Prairies. Increasingly, low temperatures will be less of a limiting factor as climate change progresses. **Combined, climate and biodiversity shifts could result in an increase in pests, diseases, and invasive species**, which can be a challenge for both crop and livestock producers if this results in increased weed, insect, or disease pressure and reduced yields (Walther et al., 2009). Pests and pathogens will be more likely to overwinter. Examples of pests and diseases that modelling shows will increase or expand include cereal rusts, the striped flea beetle, the crucifer flea beetle, the deer tick (which transmits Lyme disease), and the biting midge (which transmits bluetongue disease) (Warren & Lulham, 2021).

The forestry sector has already seen these dynamics play catastrophically, with warmer winters allowing an unprecedented spread of the mountain pine beetle in Western Canada (Kurz et al., 2008). As producers face new challenges, they will need to invest in new knowledge, equipment, and inputs to manage these pests, diseases, and invasive species.

Globally, 17%–30% of crop production is already lost to pests (Savary et al., 2019). East Africa is currently fighting a locust infestation that has been exacerbated by climate change and has pushed 42 million people into severe food insecurity (FAO, 2021). One analysis predicts that with warming temperatures, crop losses due to insect infestations alone will account for 10%–25%

of yield loss globally for major grain crops and that this will be **disproportionately higher in temperate regions such as Canada and Europe** (Deutsch et al., 2018).

3.2 Implications for Production

There are potential economic benefits for the Prairie agriculture sector due to increased crop yields and increases in farmland values (Warren & Lulham, 2021). However, while warmer temperatures and longer growing seasons may, in theory, provide benefits such as higher yields, these may be offset by negative climate impacts such as high temperatures (Sauchyn et al., 2020).

3.2.1 Implications for Crop Production

Projecting climate change impacts on specific crop yields or livestock is complex due to the intersection of physical, biological, and agronomic factors. Most research on climate change impacts focuses on four staple crops—wheat, rice, soy, and maize. Many studies do not account for climate or extreme weather impacts on yields or land value (Warren & Lulham, 2021). Rising temperatures associated with climate change have already affected crop yields globally, with the negative impacts mostly outweighing the positive ones (Challinor et al., 2014; Deryng et al., 2011; Lobell et al., 2011; Rosenzweig et al., 2013). However, it is important to note that impacts on agriculture are uneven and depend on geographies, crop type, and the degree of temperature increase.

Changes in the suitability of crops and livestock are impacted by off-farm factors such as market prices and transportation and by on-farm practices such as seeding dates, fertilization, irrigation, and more. For example, water availability historically has been the most important factor in determining yields, and with recent improvements to water management practices and new technologies, yields have improved in recent decades, even in drought years (Clearwater et al., 2016).

Table 2 summarizes examples of simulations addressing climate change impacts on the yields of major crops. In response to these changes, yields of spring wheat are expected to increase on the Prairies while canola yields will decline, with yields of hay variable between the first and second cuts. Based on various studies, including the one listed in Table 2, projections for spring wheat yields on the Prairies vary between 8% and 37% or higher by the 2050s (He et al., 2018; Qian et al., 2015, 2016; Smith et al., 2013). However, heat stress is expected to reduce canola yield in the southern Prairies (Qian et al., 2018).

The impacts described in Table 2 are not comprehensive pictures of what will happen to those crops but rather are partial estimates of impacts on specific crops of selected elements of climate change used in each particular study.

Table 2. Example simulations of climate change on yields of spring wheat, canola, and tame hay (including alfalfa)

Crop	Spring wheat	Canola	Tame hay (includes forages, alfalfa, etc.)
Anticipated change in yield (and time period)	Increase by 15%–25% (2041–2070)	Decrease by 21%–44% (2041–2070) and 23%–74% (2071–2100)	Timothy: increase of 24% for the first cut and a decrease of 31% for the second cut (2040–2069)
Climate scenario	CanESM2 and CanRCM4, RCP4.5, and RCP8.5	CanRCM4, RDP4.5, and RCP8.5	CGCM3 and HadGEM1, SRES A1B and A2
Methodology and location studied	Crop yield modelling (DSSAT) based on fieldwork from 13 locations across the Prairies	Crop yield modelling based on fieldwork in Brandon, Manitoba	Crop yield modelling based on fieldwork (CATIMO) from four locations from the Prairies
References	Qian et al., 2016	Qian et al., 2018	Jing et al., 2013

Source: Adapted from Sauchyn et al., 2020.

One factor that may affect yields is carbon dioxide fertilization. Since carbon dioxide is a key component in photosynthesis in plants, an increase in carbon dioxide in the atmosphere may lead to increased yields through increased photosynthesis—the so-called carbon dioxide fertilization effect. This effect is stronger in certain crops like wheat and maize. Overall, though, it is believed to have a minor role in changing crop yields (Intergovernmental Panel on Climate Change, 2019). Further, the effect may be declining over time (Wang et al., 2020). Ultimately, the extent that atmospheric concentrations of carbon dioxide may improve Canadian crop yields is not well known and may be offset by other impacts of climate change, such as water scarcity or heat stress during the summer.

3.2.2 Implications for Livestock Production

Climate change will impact livestock production mainly through shifts in water availability, increased extreme heat events, and the spread of new diseases and pests. There are fewer predictions of outcomes in livestock productivity due to the increased variability of management practices in livestock operations. Livestock sectors on the Prairies are likely to be affected by slower weight gain due to decreased water availability, animal death due to overheating (particularly for confined animals like chickens), and extreme weather events. As summers get warmer, heat waves could potentially increase livestock deaths, reduce milk production, and affect productivity (Rojas-Downing et al., 2017). Increases in pests could also negatively impact livestock health. Climate impacts that negatively affect the growth of forage crops and grazing capacity could have secondary impacts on livestock health if quality and availability of feed change (Kulshreshtha, 2019).

3.3 Trade, Politics, Economics, and Global Responses to Climate Change

Up to this point, we have explored how climate change might impact Prairie farmers by changing Prairie growing conditions. But agriculture is a globally traded sector, and climate change will also have impacts in an international context. There are at least three types of effects to consider:

- Climate change will change the productivity of Canada's competitors in global markets.
- Climate change-related trade restrictions may affect markets for Canadian producers.
- Climate change-related changes in consumer behaviour will alter the markets for Canadian products.

3.3.1 Climate Change Impacts for Global Competitors

The effects of climate change described in Section 3.1 will have different levels of impact in other agricultural regions around the world. Impacts such as changing crop growth rates, changing quality and quantity of livestock feed crops, crop losses to extreme weather shocks, and pest infestations will be uneven across different regions and crop types internationally. As these changes unfold, certain regions may gain comparative advantages over others in certain agricultural products or play an increased role in ensuring global food security. For example, according to the Intergovernmental Panel on Climate Change (IPCC), yields of wheat and maize in the tropics will decline with 1°C and 2°C of warming (Porter et al., 2014), compared to possible increases in yields of these crops in temperate regions such as Canada. Wealthier countries such as Canada also have more resources for adaptation in the agricultural sector (Warren & Lulham, 2021).

Extreme weather events have resulted in price spikes, export restrictions, supply chain disruptions, and social unrest (Johnstone & Mazo, 2011). An example of the geopolitical impacts of extreme weather events is the 2010 heat waves in Russia, which led to price spikes and supply disruptions in the Middle East, contributing to the escalation of Arab Spring (Welton, 2010). In addition, extreme weather shocks such as droughts and heat waves have led to reduced global cereal production, with one analysis finding losses of 9%–10% globally between 1964 and 2007 (Lesk et al., 2016).

3.3.2 Climate-Related Trade Restrictions

Some countries are responding to climate change concerns by implementing policies to reduce the environmental footprint of their food systems and promote sustainable farming practices. The European Union (EU), for example, has taken steps to transition to a sustainable food system by addressing issues around governance, public health, transparency, and sustainability through the development of their Farm to Fork Strategy (F2F), which is more comprehensive than any preceding legislation (Schebesta & Candel, 2020).

Although the F2F and other anticipated regulations are designed to address domestic concerns regarding healthy ecosystems, consumption patterns, sustainability, and resilience to climate change, they will have effects far beyond their own borders (Beckman et al., 2020). As one of the EU's major agri-food trading partners—with exports valued at CAD 1.7 billion in the first half of 2020—the F2F regulatory framework could have significant implications for Canadian producers (Government of Canada, 2020a).

Of particular note are the difficulties that will likely arise from the sustainable food labelling mandated in the F2F, for which the framework will be published in 2024, which will work to "harmonize voluntary green claims" around the nutritional, climate, environmental, and social aspects of food products (Bolla, 2020). This scheme is also expected to include animal welfare standards and labelling governing practices in animal husbandry, transport, and slaughter. Given the ambitions of the F2F to see global changes in food system sustainability, labelling initiatives could have major implications for Canada. The labelling schemes would require major improvements in chain-of-custody regulations in Canada to ensure the traceability of products through the value chain back to farms. It would also require the verification and/or certification of sustainable and ethical practices regarding crop production, as well as animal rearing, slaughter, and meat processing.

The standards will be challenging on two fronts. It is likely that they will require changes in practice for Canadian producers that want to access the EU market. And, based on historical experiences with the EU, in the context of trade under the Canada-EU Comprehensive Trade Agreement and before, there may be challenges associated with having any improved practices recognized by EU governing bodies.

Efforts are underway to improve transparency and traceability in Canadian food supply chains as well as for verifying sustainability claims, which could be implemented to meet current and upcoming regulatory standards. This includes whole supply chain approaches such as the Verified Beef Production Plus program in livestock; national participation in sustainability roundtables; adopting streamlined processes for sustainability assessment such as Field to Market and the Fieldprint Calculator; creating emissions quantification protocols for agriculture carbon offsets; and many other initiatives. Many of these initiatives are transboundary, with buy-in from many countries, including EU member states, giving them more weight than national initiatives and a higher likelihood of acceptance by the EU.

However, much remains to be done to harmonize chain-of-custody regulations going forward. This will require developing frameworks for data collection and storing and sharing along the supply chain, which could be accelerated through technologies such as blockchain (Sylvester, 2019). The food sector will need to demonstrate the green claims of their production practices using verifiable standards that will be recognized by other bodies.

If Canadian farmers want to keep or expand their market share as trusted and sustainable suppliers of food, they will likely need to adapt their practices to meet EU and other future standards. This will likely require reductions in crop protection chemicals, reductions and efficiency in fertilizer use, greater adoption of organic standards, and modifications to livestock management practices and interventions.

3.3.3 Climate-Related Changes in Consumer Behaviours

The future of the food system in Canada and the Prairies will also be affected by shifting consumer concerns around equity, ethics, sourcing, and the sustainability of food products and the food system. Customer preferences stem from an increasing awareness of the environmental and social impacts of their food choices, including values about how food is grown and how animals are raised. The impacts of some of these trends are already being realized, such as the meteoric rise of alternative meats in response to ethical and environmental concerns around livestock production (Bashi et al., 2019; Meticulous Research, 2020). With these significant shifts in what individuals want in the food they purchase come both opportunities and risks for Canadian producers.

3.3.3.1 ADOPTION OF SUSTAINABLE PRODUCTION PRACTICES

With increasing awareness of climate change and the environmental footprint of diets, consumers are more selective in the food products they consume. Canada and Prairie provinces will be required to demonstrate the sustainability of their food system—not only to continue to hold market share in places such as the EU, which are increasingly scrutinizing food production, but also to allay consumer concerns domestically. This presents a challenge for many farmers who are engaged in intensive and conventional cropping practices. However, it is also an opportunity to support producers in adopting more sustainable production practices and to highlight existing actions that are underway to improve the sustainability of agriculture production. These practices include sustainability or verification initiatives for both the livestock and crop sectors; environmentally friendly practices such as reduced fertilizer or chemical inputs through initiatives such as the "Keep it Clean" program[3]; or increasing the adoption of regenerative or organic practices that can have improved ecological outcomes. The sector can also capitalize on the ongoing quantification of the carbon and ecological benefits of practices producers engage in—such as no-till, crop rotation, shelterbelts, and the use of technology such as the variable rate application of inputs to demonstrate their commitment and contributions to the environment.

3.3.3.2 TRANSPARENCY: FARM TO PLATE

Conveying information is integral to Canada's ability to demonstrate to consumers and trading partners that producers are making sustainable choices in their production practices. One of the main ways this can be communicated is through the development of labelling schemes that provide transparency about how food was produced, processed, and transported. As mentioned,

[3] https://keepitclean.ca/

several efforts are already underway in Canada to develop the infrastructure to harmonize data collection and conveyance along the supply chain.

Canadian agriculture and farmers are part of a much larger food system and are, therefore, not immune to global dynamics. While considering the impacts of climate, trade, and the preferences of consumers, it is key that Canadian farmers recognize the opportunities and risks that will arise and how the food system can adjust and improve to meet these challenges.

3.3.3.3 PROVIDING PROTEIN

One of the largest consumer-driven climate-related trends is the shift to plant-based proteins as part of a drive to decrease the carbon footprint of consumer diets. Canada is one of the foremost producers of pulses: it was the largest exporter globally and produced over 8.7 million tonnes in 2020 (Agriculture and Agri-Food Canada [AAFC], 2020a). Pulses are a key source of plant protein, and this sector presents an opportunity for Canadian producers to increase their market share. The current value of the plant-based protein market is estimated at USD 10.4 billion and is projected to reach USD 15.6 billion by 2026, demonstrating the potential of the space (MarketsandMarkets, 2021). There have already been several large investments in this area, including the funding of the supercluster Protein Industries Canada and the construction of several pulse-processing facilities on the Prairies—priming Canada to be a major player.

The increased interest in plant-based proteins has been mirrored by stagnation in the consumption of meat products in many developed countries, which could impact the Canadian livestock sector that supplies these high-value markets (Organisation for Economic Co-operation and Development [OECD] & FAO, 2020). Heightened awareness from consumers, including of the environmental impacts of high meat consumption, provides an impetus to improve domestic livestock production techniques and maintain the viability of the sector. Demonstration of best management practices for animal welfare and verification of sustainable practices are already being developed through several of the initiatives mentioned above.

3.4 Increasing Resilience and Adapting to Climate Change Impacts

"Resilience" has been defined in different ways but generally refers to a system's capacity to withstand stresses and shocks, as well as the ability to build capacity to manage and adapt to change and to potentially transform (Bizikova et al., 2017; Bousquet et al., 2016). In the agricultural sector, resilience is the capacity to manage climate change supported by both technical capacity (equipment and infrastructure) and socio-cultural capacity (knowledge, social capital, and more). Indicators to measure resilience in Canadian agriculture have been proposed that take into consideration such factors as varying as population dynamics, the market and the economy, rural infrastructure, the natural environment, and more (Bizikova et al., 2017).

The climate change impacts described in Section 3.1 will introduce new shocks and stresses for Prairie producers, changing the way producers operate while creating increasing uncertainty.

Producers will need to build capacity and adapt to and manage changes to growing season length and precipitation, increases in extreme heat events and extreme weather events, and changes in the distribution of pests and diseases, as well as in productivity, nutrient cycling, soil quality, livestock reproductive rates, and more (Sauchyn et al., 2020; Sudmeyer at al., 2016). Producers will also need to respond to subsequent shifts in transportation, processing, and consumer demands, particularly as the rest of the world responds to climate change.

As the climate changes, agricultural producers and communities will need to invest in infrastructure and knowledge dissemination to help them adapt and build resilience. Changes in climate may also cause significant economic strain, especially for communities that are less resilient and facing existing challenges.

Climate change will also lead to physical and mental health impacts. For example, extreme weather events, such as tornadoes and thunderstorms, can be dangerous for human life, but so can extreme temperatures through heat exhaustion. Farmers and agricultural workers face unique mental health impacts from climate change, for example, stress related to drought (Yusa et al., 2015). Farming communities are not the only ones facing these hardships: both urban and rural (on reserve) Indigenous communities are already being adversely impacted by recent floods and forest fires. For example, residents of Lake St. Martin First Nation, Manitoba, were evacuated in 2011, and many have yet to return to their homes (Unger, 2020).

3.4.1 Social Dimensions of Climate Change on the Prairies

One of the key components of understanding local climate change impacts is to recognize the vulnerability of the people and communities who live there. Most vulnerability assessments focus on exposure, sensitivity, and adaptive capacity, and as a result, tend to characterize communities as experiencing vulnerability uniformly (Sauchyn et al., 2020). **New research suggests that vulnerability should be considered dynamic** and resulting from multiple factors such as race, income level, gender, (dis)ability, age, education, etc.

These factors, in turn, determine the **social infrastructure, which is the collective ability of institutions and organizations to support local economic and social well-being** (Sauchyn et al., 2020). Local knowledge and policies play a significant role in determining social infrastructure and therefore adaptive capacity and community vulnerability. While vulnerability and resilience are often described as technical issues to be resolved using technology and improved infrastructure, ensuring that social-cultural and economic supports are also addressed can help make resilience more effective and long term (Sauchyn et al., 2020).

Community vulnerability is one aspect of the culture of farming communities that plays a role in how farmers both understand and address climate change. **The community vulnerability of rural and farming communities on the Canadian Prairies is relatively high.** This is due to a smaller population size that is both older and poorer than the rest of the population (Sauchyn et al., 2020). Declining populations mean that government services have often disappeared. However, social cohesion within these communities is often higher than in urban centres, which increases access to local supports. Similarly, electoral representation is also relatively high, which can provide access to decision-making power (Sauchyn et al., 2020).

On the Canadian Prairies, social cohesion is strong among rural and farming communities, and **social capital is critical for adaptive capacity** (Fletcher et al., 2020). However, trust and reciprocity can also contribute to a strong tension with the "other," which could include farmers who are trying to change the culture of agriculture into something more sustainable. If sustainable farmers feel that they are without peers in a community and are ostracized as a result, this may dissuade them from continuing to practice these farming behaviours (Laforge & Levkoe, 2018).

Gender dynamics are particularly important to consider for Prairie agriculture due to rigid gender roles historically associated with resource-based sectors (Sauchyn et al., 2020). For example, men may experience unique physical and psychological risks in the wake of climate-related disasters due to expectations of masculinity (Alston, 2012; Fletcher & Knuttila, 2016). Research also finds that informal social capital on the Prairies may actually reinforce gender roles and inequality and exclusion, posing a barrier to effective long-term adaptation (Fletcher et al., 2020). Women play an important role on farms and in rural communities, including in response to climate change and extreme weather events, and their contributions to climate planning will be important for effective adaptation (Sauchyn et al., 2020).

Similarly, climate change impacts on agriculture will be experienced differently by Indigenous and non-Indigenous producers and communities. For example, Sauchyn et al. (2020) explain how the Blood Tribe Agricultural Producers in Alberta operate in a region vulnerable to periodic flooding. Yet, First Nations producers may have particular strengths for adaptation and resilience due to the diversity of products being produced, as well as methods such as harvesting native plants.

Canada's agricultural and food production system is also heavily dependent on foreign workers, many of whom face unique vulnerabilities due to their immigration status, lack of access to health care, and often poor working conditions (CBC News, 2021; Migrant Rights Network, 2020). Current federal agricultural worker programs deny workers the means to permanently move to Canada, despite the fact that many workers have been coming to the same farms for decades. The working conditions of many of these workers were highlighted during the pandemic when numerous meat processing plants had COVID-19 outbreaks.[4] More needs to be done to ensure the safety of both domestic and foreign workers, as working conditions are projected to be increasingly unsafe due to rising health concerns correlated with climate change, including extreme heat (Goldman et al., 2021; Yusa et al., 2015).

3.4.2 Adaptation Actions and Beneficial Management Practices

Many producers on the Prairies are already adopting changes in practices. Trends such as the adoption of no-till agriculture and increasing farm size are two examples of how agriculture

[4] The outbreak at Cargill's High River plant in Alberta resulted in 945 cases and at least two deaths among workers, including newcomers and temporary foreign workers (LeBel, 2021).

has shifted already in recent years (Sauchyn et al., 2020). Examples of adaptation actions that producers can take to increase resilience to climate change include (Sauchyn et al., 2020; Warren & Lulham, 2021):

- Using crop insurance and climate data for farm planning and risk assessment
- Changing seeding dates and cropping regimes or types
- Improved water management, conservation, and storage
- Use of drought- or heat-tolerant crop varieties
- Mixed farming approaches
- Use of precision agriculture to facilitate adaptive actions
- Planning for crop production strategies by using soil and climate data
- Monitoring livestock during heat events and using heat-abatement strategies
- Improved livestock practices (e.g., breeding, feeding, feed stockpiling)
- Improving on-farm infrastructure.

Many of the above strategies are beneficial management practices (BMPs): agricultural practices that reduce environmental risk. They are tools that farmers can use to manage and reduce environmental pollution; conserve ecosystems; preserve and improve soil, water, and air quality; and more. Often, they require only minor modifications to existing practices. We go further in depth into many BMPs in Section 6.3, where we focus on those BMPs that can significantly reduce on-farm GHG emissions. However, we stress here that many BMPs that help reduce emissions *also* offer significant adaptation-related benefits and can help producers increase resilience to climate change. For example, several BMPs can reduce input costs for producers and help increase farm economic viability. Others help strengthen local ecosystems and land management, which can increase resiliency to poor or extreme weather such as heavy moisture or flooding.

Changing production practices is a long-term challenge, and some producers are better placed than others to do so. Adaptation actions will also be inherently specific to the type of farm. For example, mixed farms may be better placed to implement certain adaptation actions, such as drought response practices, including reducing feed demand for livestock and related financial burdens (Sauchyn et al., 2020). Adaptation actions must also consider other factors, such as the economic pressures and trade and consumer trends outlined in Section 3.3, in order to avoid maladaptive strategies that actually *increase* risk and vulnerability to climate change (Sauchyn et al., 2020). There are also limits to the efficacy of certain adaptation actions. In many cases, farmers require targeted policies and support to be able to adopt adaptation actions in an economically viable way. Policies that support farmer knowledge include public research and extension services, particularly when this work is farmer-led.

Box 1. Water management, irrigation, and adaptation

Dealing with water scarcity will be one of the most significant climate change challenges for Prairie producers, and one that will require effective governance and stakeholder collaboration. Drought is a natural characteristic in the Canadian Prairies, and certain areas are more susceptible than others (such as the area in southern Saskatchewan and Alberta commonly referred to as Palliser's Triangle) (Toth et al., 2009). Prior to the 2021 summer drought, Saskatchewan had already ranked drought hazard risk as "high"; this risk could grow to "high to extreme" under certain climate change scenarios (Wittrock et al., 2018).

As producers and communities look to manage drought and water scarcity, there will likely be increasing interest in irrigation and water supplies for livestock as adaptation actions. However, irrigation is a massive water consumer and can have its own environmental impacts; it is also not a panacea. Despite most of Canadian agriculture not being irrigated, existing irrigation levels still result in the sector consuming more water than any other economic sector in Canada: annual gross water use of 4.7 billion m^3 and consumed water of about 3.5 billion m^3 (consumed water is not returned to its original source) (Natural Resources Canada, 2009). The vast majority of water withdrawals are for crop irrigation in Western Canada, and 68% of Canada's total irrigated area is in Alberta (Statistics Canada, 2019c). Recent data shows that more water is already being used to increase the resilience of irrigated crops due to dry weather conditions. This trend is increasing: in 2018, farmers used one third more water to irrigate their crops compared to two years earlier (Statistics Canada, 2019d).

There may also be significant trade-offs to irrigation use: increased agricultural water consumption could reduce water availability for other demands, impact flows in wetlands and aquatic ecosystems, and have downstream impacts when river flows or reservoirs have been reduced. For example, in the South Saskatchewan River Basin, irrigation is only practised on 5% of the land base, and yet it accounts for 90% of water consumption in the region and withdraws around 22% of natural river flow (Bruneau et al., 2009).

Irrigation alone will also not solve water scarcity challenges, as evidenced in the 2001/02 drought in Alberta, when producers lacked full water availability for their irrigation needs (Wheaton et al., 2005). The severe decline of the Colorado River basin and Lake Mead reservoir in the United States, as a result of overuse, aridication, and climate change, has already prompted mandatory water cutbacks for Arizona, Nevada, and Mexico, as well as a discussion of cutbacks for California (Wilson & James, 2021). Farmers in these regions that rely on irrigation will face severe challenges as a result of the cutoffs and water shortage.

The use and expansion of irrigation and other water use as an adaptation action will need to be carefully considered and managed as the climate changes in order to ensure wider sustainability. Long-term and proactive planning for water management and governance will be required for effective adaptation. As with flood management (Box 2), this will rely on the involvement of relevant institutions (such as watershed organizations and provincial and federal organizations) and active participation from local stakeholders and rights holders (Wittrock et al., 2018).

One of the challenges of traditional systems of extension services was the premise that "experts" would educate farmers on farming practices without incorporating the deep knowledge of farmers themselves or recognizing the diversity of farming realities in this country. Additionally, current trends in extension services do not appear to align with the urgent need to provide accurate and unbiased climate information to producers that incent more sustainable practices (Senate Committee on Agriculture and Forestry, 2018).

Adaptation goes far beyond individual producer actions (for example, it makes no sense to expect individual producers to manage impacts to transportation networks). Adaptation planning requires effective governance at multiple levels, meaningful collaboration, and consideration of diverse perspectives; local knowledge is critical to developing effective solutions (Warren & Lulham, 2021). The main challenges to adaptation planning are not necessarily information gaps (the availability and accessibility of climate change-related information continue to increase) but rather a lack of financial and human resource capacity and poor planning processes and frameworks (Waldick et al., 2017). Adaptation frameworks that improve informational flows, facilitate locally focused research and decision making, and build local capacity through government and sectoral programs are key (Waldick et al., 2017). We discuss additional economic, policy, and governance barriers and solutions for producers to adopt adaptation actions in Sections 5 and 6; this will be further explored in the second paper in this series.

3.4.3 Agroecology as an Approach to Agricultural Resiliency in Canada

There is an opportunity to rebuild extension services and public research in Canada while mainstreaming BMP adoption and supporting adaptation and stronger livelihoods among farmers more generally within the framework of agroecology. Agroecology takes a holistic approach to agricultural systems and practices by applying ecological principles to enable sustainable food systems (Gliessman, 2007).[5] It is explicitly multidisciplinary and can incorporate hard sciences (such as agronomy and environmental science) as well as economic, social, and ethical issues (Wezel et al., 2009).

As an agricultural practice, agroecology has grown in prominence since the 1980s. Wezel et al. (2009) identify three "levels" for the application of agroecology: at the plot and field scale, at the agroecosystem and farm scale, and at the food system scale. Agroecology presents a valuable approach for the adoption of BMPs at the farm level, but it can also be applied as governments develop or refine broader agricultural and food systems policies to support producers and consumers.

[5] The term is broadly used; in addition to referring to agricultural practices, it can also refer to a scientific discipline or a set of scientific principles or social movements (Wezel et al., 2009). It also has strong links to the Global South; in the social movement context, there are also links to the philosophies of Indigenous communities (for example, La Via Campesina) (IPES-Food, 2016; Rosset & Altieri, 2017).

Agroecology presents both practical and aspirational approaches to the challenges outlined in this report by building farmer livelihoods, local economies, biodiversity, resilience, and equity (Isaac et al., 2018). For example, there is significant evidence that low-input agriculture in Canada could deliver cost benefits to farmers *as well as* energy efficiency, emission benefits, and comparable yields when compared to conventional monocultures (Qualman, 2019). Yet, the key to an agroecological approach is accounting not only for economic factors but also social and cultural factors required to transition to more sustainable practices. For example, market-based policies that encourage carbon sequestration, payment for ecosystem goods and services, or carbon offsets may not be successful in the long term if they do not also address some of the social and cultural factors of agriculture.

Agroecological practice and science lend themselves to a more participatory approach that emphasizes building relationships between researchers and farmers and results in more relevant research (Warner, 2008). Farmer-to-farmer learning can also help develop local farmer knowledge in BMPs and agroecology, but these networks remain limited on the Prairies (Laforge & McLachlan, 2018). One example that is already taking place in Canada is participatory plant breeding. A program supported by the Bauta Family Initiative on Canadian Seed Security (n.d.) and the University of Manitoba "supports farmers as early-generation plant breeders, selecting for varieties that are adapted to their regional climate and farm needs. The program is focused on wheat, oat, potatoes, and corn."

Researchers with AAFC have called for more studies of agroecology in Canadian production, which would also support research on climate change mitigation, adaptation, and conservation (Brandt et al., 2010). Currently, very little research in Canada supports producers in the complexities of establishing agroecological farms.[6] Research has also tended to focus on productivity comparisons between agroecological and conventional systems or environmental services of agroecological practices, or they evaluate potential enhancements in biologically diverse agroecosystems through practices such as intercropping and agroforestry (Isaac et al., 2018). **More could be done to establish organizations like the Ecological Farmers of Ontario, which conducts significant farmer-led research projects** (Isaac et al., 2018). Likewise, the federal government funding for the Organic Science Cluster provides an opportunity to expand research.

[6] A small research program at the University of Manitoba does exist, but it is fairly limited (Laforge & McLachlan, 2018).

Further Reading

Bush, E., & Lemmen, D. (2019). *Canada's changing climate report.* Government of Canada. https://changingclimate.ca/site/assets/uploads/sites/2/2019/04/CCCR_FULLREPORT-EN-FINAL.pdf

Isaac, M. E., Ryan S., Isakson, B. D., Levkoe, C. Z., Hargreaves, S. K., Méndez, V. E., Wittman, H., Hammelman, C., Langill, J. C., Martin, A. R., Nelson, E., Ekers, M., Borden, K. A., Gagliardi, S., Buchanan, S., Archibald, S., & Gálvez Ciani, A. (2018). Agroecology in Canada: Towards an integration of agroecological practice, movement and science. *Sustainability: Special Issue on Agroecology for the Transition Towards Social-Ecological Sustainability, 10*(3299), 1–23. https://doi.org/10.3390/su10093299.

Li, G., Zhang, X., Cannon, A. J., Murdock, T., Sobie, S., Zwiers, F., Anderson, K., & Qian, B. (208). Indices of Canada's future climate for general and agricultural adaptation applications. *Climatic Change, 148,* 249–63. https://link.springer.com/article/10.1007/s10584-018-2199-x

Sauchyn, D., Davidson, D., & Johnston, M. (2020). Prairie provinces. In F. J. Warren, N. Lulham, & D. S. Lemmon (Eds.), *Canada in a changing climate: Regional perspectives report.* Government of Canada. https://www.nrcan.gc.ca/sites/nrcan/files/earthsciences/Prairie%20Provinces%20Chapter%20%E2%80%93%20Regional%20Perspectives%20Report.pdf

Warner, K. D. (2008). Agroecology as participatory science: Emerging alternatives to technology transfer extension practice. *Science, Technology, & Human Values, 33*(6), 754–77.

4.0
The Impacts of Prairie Agriculture on Climate Change

Any major economic activity produces GHGs, and agriculture is no exception. This is not surprising; producing the food that sustains us is one of the most significant human undertakings, and its impacts are on par with its scale. Addressing climate change means that, like other economic sectors, agriculture must undergo a low-carbon transition, including reducing the use of fossil fuels and the inputs derived from them. While this presents a daunting challenge, the good news is that many of the emissions caused by modern agricultural practices are within the capacity of producers to control through management techniques that also benefit producers, and there are policies that can support these practices. This chapter first looks at the ways that agriculture on the Canadian Prairies contributes to the climate change challenge and then explores the ways in which agricultural practice can help address that challenge, focusing on ways that also contribute to farm-level viability and resilience.

Key Messages:

- Cumulatively, agriculture in the Prairie provinces represents 64% of Canada's agricultural emissions and over 6% of Canada's total emissions.
- Agricultural emissions include methane, nitrous oxide, and carbon dioxide from a variety of both on- and off-farm sources, including input use and production, livestock-related practices, land management, and energy use.
- Implementing improved management practices can significantly reduce on-farm emissions while providing tangible co-benefits for biodiversity and producer and community resilience.

4.1 Canadian Agriculture-Related Emissions

The Paris Agreement, the world's legally binding agreement on climate change, aims to reduce GHG emissions to limit global warming to below 2°C, striving for 1.5°C. Reducing agricultural emissions is an integral component of this target. Research shows that if significant efforts are not made to reduce emissions from global food and agriculture systems, it could be impossible to achieve the 1.5°C target and would seriously jeopardize the 2°C target (Clark et al., 2020). As we have seen in Section 3, even current levels of global temperature rise can have significant negative impacts on farmers.

Across Canada, agriculture accounts for 8%–12% of the country's GHG emissions.[7] These emissions mainly come in three forms:

[7] This range exists since emissions accounting systems account for agricultural emissions in different ways. The standard federal system disaggregates emissions by economic sector, unlike the IPCC approach, which does not include on-farm fuel use in the agriculture category (Clearwater, 2016; Environment and Climate Change Canada, 2020b).

- **Nitrous oxide (N_2O)** comes mainly from nitrogen in our soils (which is mostly from applying synthetic nitrogen fertilizer), with some from manure management and some occurring naturally.
- **Methane (CH_4)** comes mainly from cattle as they digest grass (enteric fermentation),[8] as well as manure management and decomposition.
- **Carbon dioxide (CO_2)** comes mainly from burning fossil fuels on-farm; producing electricity used on farms; producing farm inputs (fertilizers, chemicals, machinery, etc.); and liming and urea application.

Emissions from nitrous oxide and methane have significantly higher global warming potential than carbon dioxide—by factors of 21 and 310, respectively, over a 100-year time frame—meaning that their impacts on climate are high. Agriculture accounts for 76% of Canada's nitrous oxide emissions and 31% of Canada's methane emissions (Environment and Climate Change Canada [ECCC], 2020b).

In this section, we use emissions data from the federal GHG emissions reporting system (Clearwater, 2016; ECCC, 2020b). Canada uses an "economic sector" approach to measuring emissions. In the "agriculture" category, they include nitrous oxide and methane emissions from the sector, as well as on-farm fuel use from field operations, farm transport, and heating. However, these statistics do *not* include agriculture-related emissions from electricity; certain heating, such as grain drying; production of machinery and agrochemicals (e.g., fertilizer); and certain land-use emissions.[9]

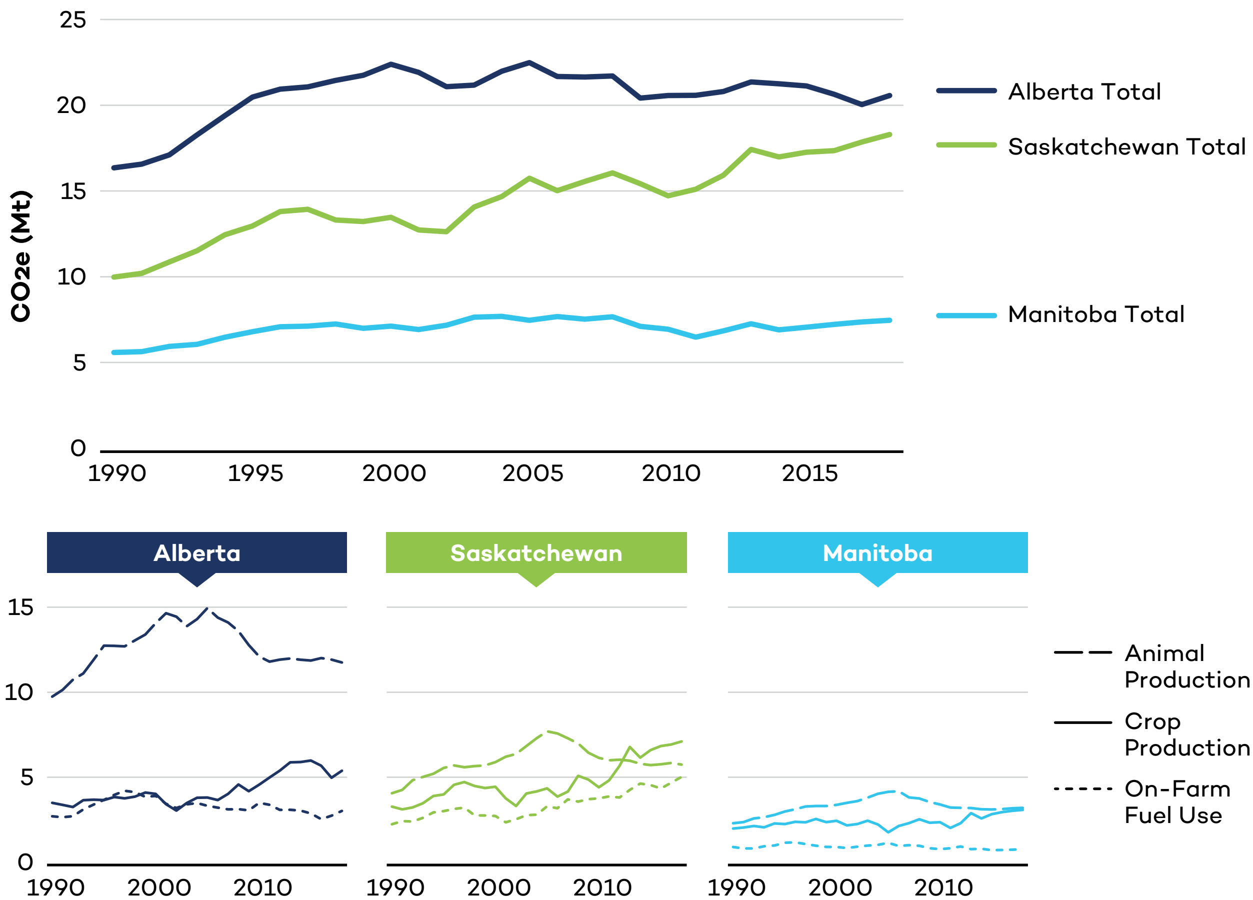
4.2 Agriculture-Related Emissions in Prairie Provinces

Agriculture-related GHG emissions in Prairie provinces represent the bulk of Canada's agricultural emissions. Table 6 gives a snapshot of on-farm Prairie emissions and their sources. Total Prairie emissions have been trending upward: compared to 1990 emissions, they have increased by 25% in Alberta, 81% in Saskatchewan, and 32% in Manitoba (ECCC, 2020a). Since 2005, the reference year for the Paris Agreement, agricultural emissions have grown less than 1% in Manitoba and have dropped by 8% in Alberta. However, they have grown 15% in Saskatchewan, largely due to on-farm fuel use and crop production-related emissions (ECCC, 2020a) (see Figure 6). Increases in emissions since 1990 were primarily due to pronounced increases in input use (see Figure 2) and the increase of certain types of production, including canola. The adoption of no-till agriculture has helped to reduce emissions.

[8] Over 95% of Canada's enteric fermentation emissions come from cattle (Environment and Climate Change Canada, 2020b).

[9] An estimate by the National Farmers Union that incorporated these emissions found that agriculture represented 12% of Canada's total GHG emissions (Qualman, 2019).

Figure 6. Agricultural emissions in Prairie provinces, 1990–2018 (Mt CO_2e)



Source: Data from ECCC, 2020a.

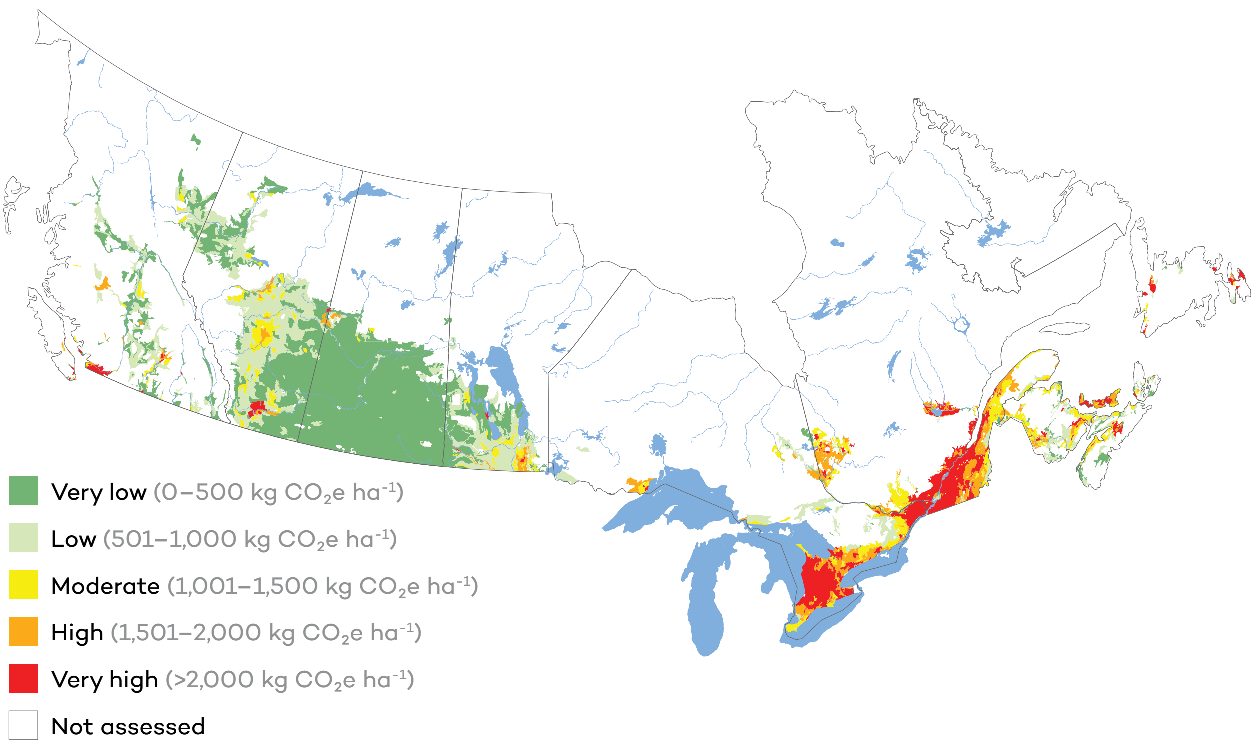
Table 3. Prairie agricultural emissions by province and source, 2018

	GHG emissions in the Canadian Prairies (Mt CO_2e)			Prairie totals as a percentage of Canadian totals
	Alberta	**Saskatchewan**	**Manitoba**	
On-farm fuel use	3.23	5.23	0.98	69%
Crop production	5.59	7.31	3.28	68%
Animal production	11.96	5.95	3.41	60%
Total	**20.77**	**18.5**	**7.67**	**64%**

Source: Data from ECCC, 2020a

While the Prairies are significant in terms of absolute amount of emissions (Table 3), GHG intensity per hectare of land is lower compared to other regions of Canada (Figure 7) (Clearwater et al., 2016). Intensity per hectare increases in areas of livestock production. Many reasons for regional variations in emissions intensity exist, including production methods as well as regional climatic and land differences. For example, soil and climatic conditions on the Prairies are ideal for no-till, while the wetter climate in Eastern Canada enables more nitrous oxide formation and related emissions (Clearwater et al., 2016).

Figure 7. Net agricultural GHG emissions per hectare of land (kg CO_2e ha^{-1}), 2011



Source: Clearwater et al., 2016.

Thanks to decreases in emissions intensity, the rate of overall agricultural emissions growth has slowed in more recent years. Over the past 30 years, increased uptake in no-till practices on the Prairies has reduced soil disturbance and helped sequester carbon (Clearwater et al., 2016).

4.2.1 GHG Emissions for Specific Types of Production

Agriculture is highly regionalized across Canada—75% of Canada's beef cattle and over 90% of wheat, barley, and canola are produced on the Prairies (ECCC, 2020b). Each type of production has different profiles and emissions rates. Table 4 shows average emission rates for the Prairie provinces' three main crops—canola, spring wheat, and tame hay—on both a per-crop-area basis and per kilogram of dry matter (DM). These numbers are weighted averages that consider regional differences such as precipitation and soil conditions, as well as different farm-level practices. Note that, on average, canola has almost twice the GHG emissions per kg of DM as spring wheat, which is twice as GHG intense per weight again as tame hay.

Table 4. GHG emission rates for select crops in Canada

	Canola		Spring wheat		Tame hay	
Province	**kg CO_2e/ ha**	**kg CO_2e/ kg DM**	**kg CO_2e/ ha**	**kg CO_2e/ kg DM**	**kg CO_2e/ ha**	**kg CO_2e/ kg DM**
Alberta	1,300	0.65	980	0.34	680	0.17
Saskatchewan	1,040	0.63	680	0.30	540	0.15
Manitoba	1,280	0.88	1,170	0.53	790	0.19
Canada	**1,360**	**0.78**	**1,120**	**0.40**	**860**	**0.18**

Source: Clearwater et al., 2016.

Rates of emissions for livestock are much harder to estimate at a general level. This is due to the differences in production practices, such as pasture-raising beef versus grain-feeding beef, but also due to differences in how animals are used, including whether animals are harvested just for meat or if they are processed for leather, offal, and rendering products. Thus, emissions intensity rates for livestock are too complex to summarize and compare in the same way as is possible with crops (such as in Table 4). However, there is evidence that emissions intensity has decreased with beef production from 1991 to 2006 due to improved animal diet, lower GHG emissions for forage crop production, and an increase in average carcass weight (Clearwater et al., 2016). In Western Canada, this has resulted in a decline from 13.8 kg CO_2e per kg (live weight) in 1991 to 8.4 kg CO_2e per kg (live weight) (Clearwater et al., 2016).

4.3 Reducing Emissions Through BMPs

Adopting sustainable production practices and farm management techniques, such as BMPs, can have big impacts on GHG emissions. However, many of these changes need policy and industry support in order to make them economically viable for producers. Some emissions reduction efforts will require minor adjustments, and others will require significant on-farm changes in production practices that will require new knowledge systems, equipment, and infrastructure, while still others only require a minor adjustment in current practices.

Many Canadian farmers have already taken steps to improve efficiency and reduce emissions on their farms because it is economically and financially useful to do so. Farmers are also innovators and stewards—they know it is important to protect the soil, water, and air that they rely on for their livelihoods and are committed to finding new ways to protect the environment for all Canadians. Organizations such as Farmers for Climate Solutions have demonstrated the commitment of many Canadian farmers to this transition.

Below we go into more depth on the three main types of on-farm emissions and highlight some of the ways they can be reduced.

4.3.1 Nitrous Oxide

Nitrous oxide is emitted from both anthropogenic and natural processes. Global human-induced nitrous oxide emissions have increased by 30% over the last 40 years, rising faster than some of the IPCC's most pessimistic projected emissions scenarios (Tian et al., 2020). Reducing emissions from nitrous oxide is a priority for producers and policy-makers since they are a major portion of agricultural GHG emissions.

Nitrous oxide's main agricultural sources are synthetic nitrogen fertilizer use and production, and to a lesser extent, manure management.[10] In 2018, synthetic nitrogen fertilizer use (not production) accounted for 38% of agricultural nitrous oxide emissions in Canada, while manure management accounted for 14% (ECCC, 2020b). Precipitation is one of the most significant factors in determining emissions intensity; although higher precipitation results in higher yields, it also results in higher nitrous oxide emissions.

Nitrogen fertilizer use has increased significantly in Canada (see Figure 2), including in Prairie provinces, up 72% since 2005 and double that of 1990 levels (ECCC, 2020b).[11] Manure-related nitrous oxide emissions have also increased, although they are less than half of emissions from fertilizer-related use, and the increase has only been 12% from 1990 levels (ECCC, 2020b).

Nitrogen fertilizer production is also an important source of GHGs; its manufacturing process produces a stream of nitrous oxide waste, and it typically uses natural gas as a fuel for industrial heat, producing significant amounts of carbon dioxide (Qualman, 2019; Tian et al., 2020). As well as producing GHG emissions, nitrogen fertilizer use has other negative environmental impacts. Nitrogen runoff from agriculture results in the over-nitrification of waterways, which can cause "dead zones" where low oxygen levels result in the loss of biodiversity. Nitrous oxide is also a significant ozone-depleting gas.

Nitrogen fertilizers are a significant input cost for farmers. They are most frequently used on grain and some oilseed crops, with canola generally having the highest rates of application.[12]

---

[10] Nitrous oxide is also emitted from agricultural soils through crop residue decomposition and other indirect or minor sources (Environment and Climate Change Canada, 2020b).

[11] Nitrous oxide (N_2O) emissions occur when nitrogen (N) in ammonia is applied as a fertilizer and through the processes of volatilization (nitrogen converted to a gas) and the subsequent leaching and runoff (nitrogen is dissolved in water).

[12] For example, suggested fertilizer application levels can be found in provincial crop planning guides (e.g., see Saskatchewan's 2019 *Crop Planning Guide:* https://publications.saskatchewan.ca/#/products/92833)

However, research by Dale (2020) found that it is challenging for farmers to access and apply adequate amounts of non-synthetic fertilizers in ways that are both feasible and ecologically sustainable. Enriching soil through select crops, or "green manure," requires land being out of production for a given season, which can add significant economic pressure (Dale, 2020). In the short run, or absent financial incentives, the easiest potential solution to reduce nitrogen fertilizer use is the 4R nutrient stewardship. This BMP increases fertilizer efficiency and reduces emissions by applying fertilizers:

- in the **right** place,
- at the **right** time,
- in the **right** amount, and
- using the **right** fertilizer formulation or product.

Subsurface placement of fertilizer at seeding time below the surface of the soil rather than applying on the soil surface would optimize fertilizer placement (the right place) while also reducing application rates (the right amount, which can also be facilitated through precision agriculture). This would act to immediately cut emissions while reducing nitrogen losses and delivering more nutrients to crops. Applying fertilizers in the spring rather than in fall also reduces emissions (the right time). Public research on optimizing fertilizer types and coatings (the right product) could help producers further reduce emissions. A critical component of the success of this BMP is having public and independent soil scientists who support farmers in testing, interpreting, and understanding the impacts of nitrogen use on crop yields, GHG emissions, and pollution, and holistic approaches to soil health (Qualman, 2019).

The need for a comprehensive approach to reducing emissions and supporting soil health would also include BMPs that support cover cropping or increase the production of pulses and other legumes. Cover crops can reduce nutrient leaching, scavenge nutrients that other crops may not be able to access, assist in reducing erosion, and improve soil organic matter (Chatterjee & Clay, 2020). Legume crops typically require no nitrogen fertilizer; rather, they fix nitrogen from the air and bring it back into the soil, making this nitrogen available to crops in subsequent years. Consumer demand for pulses and legumes is increasing, providing market demand that supports farmers in making this BMP transition (Pratt, 2020). This could also include the use of "green manure" applications: the incorporation of crops such as clover or beans into the soil before they are mature to improve soil fertility. Younger legume crops can also be used as feed for cattle and have been shown to reduce methane emissions in cattle because they are easy to digest (Qualman, 2019). However, the dynamics between cover crops and nitrous oxide emissions from soil are complex: in some cases, cover crops can indirectly reduce nitrous oxide, but in others, they may not (Basche et al., 2014). While cover crops provide a host of benefits, proper management strategies will be needed to reduce potential increases of nitrous oxide emissions from their use (such as controlling the timing and rate of inputs or limiting manure and legume crops in the same location) (Saha et al., 2021).

Improving manure management can also reduce nitrous oxide emissions. In fact, 51% of manure management-related emissions in Canada are nitrous oxide (ECCC, 2020b). Manure handling and storage emits both methane from anaerobic decomposition and nitrous oxide from storage and application to soils (Government of Alberta, 2004). Nitrous oxide emissions are an indirect result of volatilization when ammonia (NH_3) and nitrogen oxides (NO_x) are emitted from manure (Montes et al., 2013).[13] This is discussed further in the next section on methane since manure management can also reduce emissions here.

4.3.2 Methane

Methane emissions are primarily the result of animal production, with cattle and other ruminants[14] being a major contributor. Methane is emitted when plant material and manure decompose under anaerobic conditions, either within an animal's digestive system or due to ineffective manure management (Montes et al., 2013).

While enteric fermentation emissions grew substantially in Canada from 1990 to 2005, since 2005 they have dropped by 22% due to changes in feeding (ECCC, 2020b). As for manure management-related emissions in Canada, beef cattle are responsible for 42% (30% methane and 70% nitrous oxide) (ECCC, 2020b). Methane emissions from manure from swine are also significant. Both beef and swine populations have decreased on the Prairies since 2005, although overall, Canada has seen a population increase in these animals. Declining cattle and pork populations on the Prairies are largely the result of reduced prices due to changes in consumer demand (Clearwater et al., 2016).

Manure management systems in Canada are generally either liquid storage (common in swine and dairy production), solid storage or drylot (most common in feedlot beef production), or pasture and paddock (usually low-density pasturing), with biodigesters and composting being less common (Clearwater et al., 2016; ECCC, 2020b). The two main factors that impact methane emissions are the quantity of manure and the amount that decomposes anaerobically (Eggleston et al., 2006). The former is impacted by the number and type of livestock, and the quantity, quality, and digestibility of their feed (Government of Alberta, 2004). The latter is impacted by how manure is stored, including moisture, temperature, and length of storage. Overall, methane production can be anywhere from four to 20 times as high in liquid storage (e.g., in lagoons or tanks) and handling compared to solid storage (e.g., in piles) (Eggleston et al., 2006). Manure applied to soil generally means less methane is produced than when in storage.

On the Prairies, solid or composted storage is by far the most common method used. For example, in 2016, 20,569 Prairie farms were using solid or composted manure, while under 2,000 farms were using liquid manure (Statistics Canada, 2018c). Of those using solid or composted

[13] There are few direct nitrous oxide emissions from manure storage itself, but when manure is handled aerobically and applied to pasture, both nitrification and denitrification processes can occur and form nitrous oxide (Montes et al., 2013). Nitrous oxide can also be lost from open surfaces of beef and dairy feedlots (Montes et al., 2013).

[14] Ruminants include all bovines, wild and domesticated, as well as sheep, goats, and deer.

manure, 54% of farms were incorporating manure into the soil.[15] Typically, farms spreading manure need less fertilizer than those that do not. While there have been positive changes over the past decade regarding better application and storage of manure, both emissions and nutrient runoff from manure management represent a significant challenge for the sector and present many options to improve on-farm practices (Clearwater et al., 2016).[16]

Acting to reduce methane emissions has an almost immediate effect since methane is relatively short-lived in the atmosphere (Qualman, 2019). The BMPs for the reduction of methane emissions break down into two streams: low-emission animals, mostly through feed management, and low-emission manure handling (Henderson et al., 2020).

For feed management, this means avoiding the oversupply of feed protein. There is some evidence that supplementing cattle feed with edible oils can reduce emissions from enteric fermentation in ruminants, although the cost and logistics of supplementing remain barriers (Bayat et al., 2018; Clearwater et al., 2016). Other forms of supplements, such as certain species of seaweed, have also shown significant results in reducing methane emissions from cattle (Roque et al., 2019). In poultry and swine production, reducing the overfeeding of protein can also reduce methane in manure.

Better manure management includes low-emission application methods (i.e., injection or rapid incorporation), composting, using biodigesters to collect methane for heat or electricity from sealed manure-storage units, dry storage of manure, and storing manure for a shorter time. The less time manure spends in storage before application and incorporation into soils, the lower the amount methane produced from anaerobic decomposition. The easiest way to accelerate incorporation is through rotational grazing of cattle on pastures, since the heavy hoof “traffic” will integrate manure more than in regular grazing situations, particularly if pastures have incorporated nutrient-dense legumes (Stinner et al., 1997). Rotational grazing, also called mob grazing, can also help sequester carbon in the soil through the establishment of complex root systems of pasture plants, particularly in carbon-poor soils (Dale, 2020).

Many of the methane-related BMPs require a financial investment by farmers in new equipment, infrastructure, and knowledge—policies that support this transition are required for these practices to become more common.

4.3.3 Carbon Dioxide

Federal statistics indicate that around a fifth of agricultural emissions on the Prairies come from on-farm fuel use (ECCC, 2020b). This includes fuel used for on-site transport (tractors and

[15] Nitrous oxide emissions from using manure as a fertilizer are captured in the “Agricultural Soils” category in federal GHG emissions accounting. It is responsible for around 200 kt CO_2e per year—relatively insignificant compared to synthetic and organic nitrogen fertilizers (Environment and Climate Change Canada, 2020b).

[16] Statistics Canada’s *Farm Environmental Management Survey* (2011) contains significant detail on trends in on-farm practices. See: https://www150.statcan.gc.ca/n1/en/pub/21-023-x/21-023-x2013001-eng.pdf?st=zjvfrOkR

other machinery) and process emissions where fuel is burned on-site (e.g., for grain drying). Other carbon dioxide emissions from agriculture also come from electricity use and from off-farm sources such as machinery manufacturing and fertilizer production (these manufacturing emissions are not counted in the one fifth figure cited above). Fuel and electricity costs for on-farm operations can represent substantial costs for farmers and ranchers, so reducing fuel use can have double benefits: reducing both GHG emissions and operating expenses.

Rates of carbon dioxide emissions have declined somewhat in Canada in the past few decades due to a combination of improved efficiency in farm equipment and changes in farm management practices (Clearwater et al., 2016).

4.3.3.1 ON-FARM MACHINERY USE

Tractors provide the main source of power for on-farm operations. Over the past two decades, the number of tractors per farm in Canada has increased, partly due to farm consolidation (Statistics Canada, 2018d). While total numbers of tractors reduced slightly from 2011 to 2016, the numbers of large tractors (above 149 horsepower) have increased substantially, including on the Prairies (Statistics Canada, 2018a, 2018d). Since farm machinery tends to have an extended life compared to other vehicles, it is common to find decades-old machinery on farms, in particular on smaller operations (California Air Resources Board, 2018). Additional research is needed to determine in what situations it may be more fuel efficient to use older versus newer machinery.

4.3.3.2 GRAIN DRYING

Most harvested grain is stored on-farm (Jayas & White, 2003). As grains with high moisture levels are more likely to spoil, grain drying with heat is a crucial process for farmers to be able to harvest and sell crops in wet years and years with late harvests. Grain drying with heat can be fossil fuel-intensive since it is primarily done using propane or natural gas. The costs for producers can also be significant. Grain drying emissions data for the Prairies are not readily available. However, for comparison, the Government of Ontario (2017) has estimated that for 8.5 million tonnes of corn grain produced each year in the province, 450 kt CO_2e is produced from grain drying. A 20% reduction in grain drying fuel would reduce Ontario's emissions the same amount as taking 19,000 passenger cars off the road (Government of Ontario, 2017).

4.3.3.3 MACHINERY MANUFACTURING EMISSIONS

While recent data on machinery manufacturing emissions is not readily available, Dyer & Desjardins (2006) estimated machinery manufacturing emissions to be up to 6 Mt CO_2e in 1996, with the energy required for manufacturing representing almost half the amount of energy consumed by the machinery during farm field work. In 2011, machinery manufacturing emissions accounted for 18% of all agricultural energy use and fossil fuel consumption emissions (Clearwater et al., 2016). Machinery manufacturing emissions are heavily related to the type of material used, and the largest reductions in emissions in recent years have come from the use of recycled steel (Dyer & Desjardins, 2006).

4.3.3.4 PESTICIDE USE AND PRODUCTION

The Prairies have a higher percentage of land treated with pesticides compared to other regions in Canada. However, there is no disaggregated data readily available on GHG emissions directly from pesticide production and application in Canada.[17]

Emissions from pesticides vary by crop and local conditions. On the Prairies, pesticide use in durum wheat production is generally lower than for canola and pulses since there is a higher likelihood of diseases in broadleaf crops (Gan et al., 2011). The adoption of no-till systems has actually led to increased use of pesticides (Clearwater et al., 2016). As with other crop inputs, pesticide application requires significant fuel. For example, the use of a 50-foot boom sprayer uses 0.84 litres of fuel per hectare, while a sprayer pulled by a fuel-powered tractor would be even higher (Brookes & Barfoot, 2017). Notably, pesticide application increases in response to invasive species, which could become more of a threat under climate change. For example, a study in the United States found annual emissions of 4 to 60 Kt CO_2e related to the application of pesticides in response to the soybean aphid, an invasive agricultural pest from Asia (Heimpel et al., 2013).

In an attempt to capture both manufacturing and use-related emissions, Audsley et al. (2009) calculated emissions and the global warming potential of different pesticides. They tracked both process energy (from energy used in manufacturing) and inherent energy (energy used in production but maintained in the pesticide's chemical structure), finding that around 9% of total energy use for arable crops globally came from pesticide manufacturing—higher for potatoes and lower for spring crops.

4.3.3.5 ADDRESSING ON-FARM CARBON DIOXIDE EMISSIONS

Reducing carbon dioxide emissions can result from:[18]

- Improving fuel efficiency for farm equipment and buildings
- Using alternative fuels (including electrification of vehicles and equipment)
- Reducing transportation distances for grains and livestock to be processed and for inputs to be produced
- Equipment sharing to reduce the manufacturing emissions of new equipment.

On Prairie farms, farmers have always been improving efficiency, and leveraging this tendency can help to reduce emissions. As equipment needs to be replaced and buildings upgraded, farmers will generally choose the most cost-effective options, which includes factoring in the costs of operating, including fuel costs. Without the manufacturing of fuel-efficient and affordable options, there are limits to what farmers can do on their farms with respect to farm equipment and

[17] Difficulty in assessing emissions related to pesticide manufacturing stems largely from a lack of data on pesticide manufacturing processes and energy use (in particular from companies themselves) (Aktar et al., 2009; Audsley et al., 2009).

[18] Our focus here is on-farm emissions, and so we do not focus on processing emissions, and only on upstream (input and equipment manufacturing) emissions to the extent that farm practice can reduce their end use.

infrastructure, including buildings, pumps, refrigeration, lighting, etc. For example, electric cars are becoming more common and have seen support from governments and industry in Canada; however, fleets of electric tractors and farm equipment remain in early phases.

The emissions intensity of electricity is also an issue: while Manitoba's electricity is powered mainly through hydroelectricity, Alberta and Saskatchewan rely heavily on fossil fuels (coal and natural gas). Thus, the emissions reductions from switching to battery-electric farm equipment may be limited in those provinces until cleaner forms of electricity production are adopted.

Most of the routes to reduced carbon dioxide emissions are costly, at least in terms of upfront costs, if not overall. In order to support farmers in reducing carbon dioxide emissions on their farms, further policy supports are needed, including grants and financing for energy efficiency retrofits for buildings, improving building standards for new homes and buildings, and even establishing on-farm renewable energy production. Equipment sharing has a history on the Prairies but faces ongoing challenges due to the short time periods in which equipment is used.

4.4 The Role of Soil, Water, and Land Management

Healthy soils and water mitigate climate change emissions. They can also insulate farmers from climate-related impacts (discussed in Section 3). Increasing attention is being paid to how properly managed agricultural lands can contribute to climate change mitigation while delivering biodiversity co-benefits.

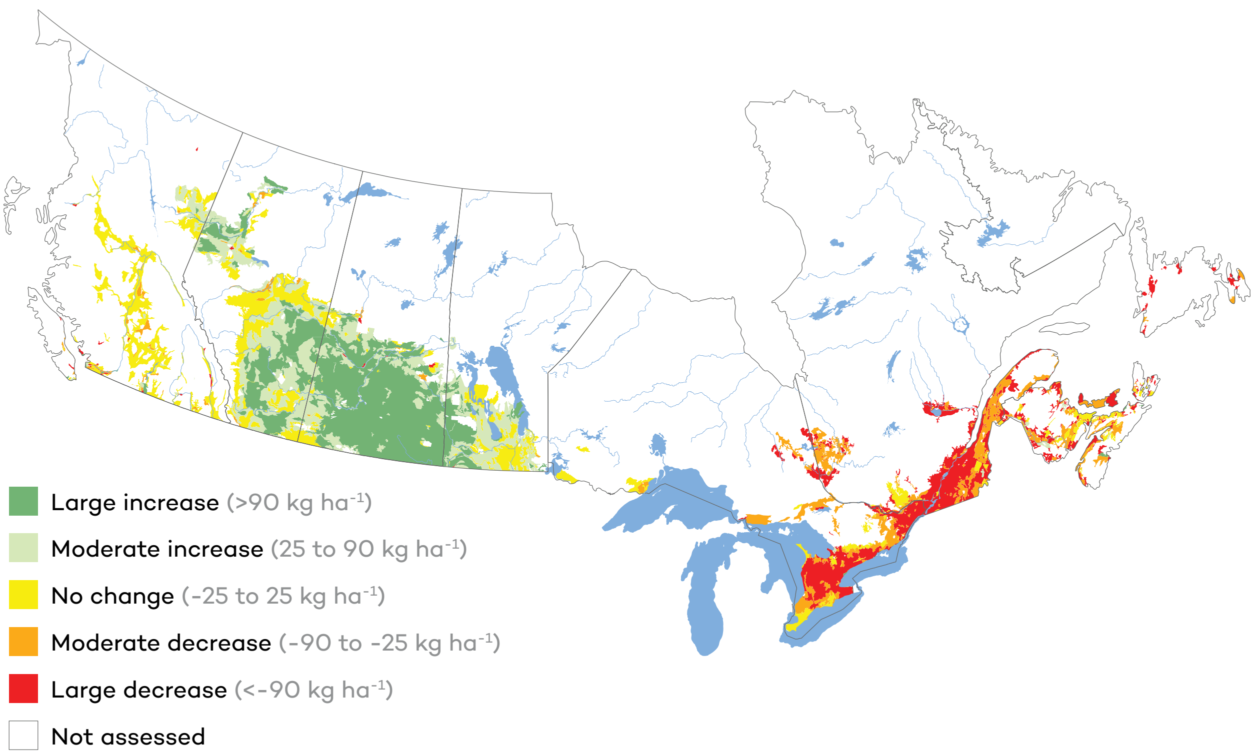
Healthy soils can act as carbon sinks and have lower rates of nitrous oxide and methane emissions. Healthy waterways can support nutrient cycling, including nitrogen, and can also protect producers from climate change effects by providing overflow for extreme flooding events and storing water during low precipitation years. Healthy soil and ecosystems also promote biodiversity, which gives producers an indirect advantage by providing more pollinators and soil microbes. Soil and water systems are interconnected and require integrated management.

Put simply, healthy soils with more microbial and fungal organisms will sequester more carbon than "dead" soils. Minimizing soil disturbance and ensuring healthy soil ecosystems, for example, by planting cover crops, helps build soil organic carbon or sequester carbon (Dale, 2020). Proper soil and water management can also improve farm productivity and limit erosion-related issues, including pesticide runoff (Clearwater et al., 2016; Gan et al., 2011). It can also help build resiliency to climate change, as practices like cover cropping help keep moisture in the soil and reduce impacts from drought.

By contrast, practices such as conventional tilling, overuse of fertilizer and pesticides, and increased production of annual crops or monocultures can lower soil cover levels and deplete soil health by damaging critical rhizomes and microbes within the soil (Clearwater et al., 2016; Dale, 2020; Magdoff & van Es, 2010). Erosion causes topsoil to be removed by wind and water, and the oxidization of soil organic matter contributes to soil-related GHG emissions.

Soil cover levels (soil covered by vegetation or crop residue) have increased over the past 3 decades, largely due to decreased use of summer fallow[19] and wider adoption of no-till and zero-till land management practices (Clearwater et al., 2016). On the Prairies in 2016, no-till or zero-till practices were applied on 65% of agricultural land prepared for seeding, compared to only 16% in 1996 (Statistics Canada, 2018b). Due to better soil and land management practices, soil organic carbon levels have increased recently so that agricultural soils in Canada are no longer the source of emissions they were in the 1980s, now representing a net carbon sink (see Figure 8). However, it is important to note that there are eventually diminishing returns on carbon sequestration as healthy soils increase their carbon storage and reach a new equilibrium state (Paustian et al., 2019). As well, effective soil carbon sequestration relies on ongoing management, as carbon can be lost to the atmosphere due to changes in land management.

Figure 8. Annual soil organic carbon change in Canada (2011)



Source: Clearwater et al., 2016.

Shelterbelts—trees planted to reduce erosion—can contribute to soil health and farm viability by reducing erosion while also limiting water contamination and supporting wildlife (Clearwater et al., 2016). In 2011, 54% of Canadian producers were maintaining buffers on all cropland next to waterways. However, producers are less likely to maintain riparian buffers around seasonal

[19] The practice of weed control and an effort to increase moisture in soil by leaving a field without a crop for a period of one year.

wetlands, as these areas can sometimes be used for crop production. It should also be noted that the expansion of agricultural land also has significant implications for the ability of ecosystems to sequester carbon and maintain biodiversity—wetlands and native grasslands continue to decline on the Prairies.

A recent study by Nature United shows that, across Canada, natural climate solutions in agriculture (such as cover cropping, managing crop residues, tree intercropping and silvopasture, and manure and nutrient management) could contribute 37.4 Mt CO_2e per year in emissions reductions by 2030—nearly *half* of what is achievable through all natural climate solutions across Canada in the same time period (Drever et al., 2021). Supporting producers to maximize on-farm carbon sequestration and conservation is an important tool in the climate action toolbox. The Alternative Land Use Service (ALUS) model (Section 5.4.1) demonstrates the successes that can be achieved for climate change, biodiversity, and producer livelihoods when such an approach is taken. There are also successful examples from other countries, such as New Zealand's Hill Country Erosion Programme (Government of New Zealand, 2020).

Pursuing holistic agricultural practices that directly tackle emissions while incorporating biodiversity issues will be critical to ensuring healthy soils and water, supporting the sustainability of the sector, and increasing producer resiliency in the face of climate change. It is important to note that healthy soil practices are context-specific and can include a range of other strategies, such as organic amendments, diverse crop rotations, avoiding soil compaction, integrated pest management, improved grazing practices, and more (Equiterre & Greenbelt Foundation, 2021). In their report *The Power of Soil*, Equiterre and the Greenbelt Foundation (2021) outline a series of policy changes, partnerships, and funding programs that could support soil health through a comprehensive, systems-level approach.

Further Reading

Clearwater, R. L., Martin, T., & Hoppe, T. (Eds.). (2016). *Environmental sustainability of Canadian agriculture* (Report #4 Agri-Environmental Indicators Report Series). Agriculture and Agri-Food Canada.

Drever, C. R., Cook-Patton, S. C., Akhter, F., Badiou, P. H., Chmura, G. L., Davidson, S. J., Desjardins, R. L., Dyk, A., Fargione, J. E., Fellows, M., Filewod, B., Hessing-Lewis, M., Jayasundara, S., Keeton, W. S., Kroeger, T., Lark, T. J., Le, E., Leavitt, S. M., LeClerc, M.-E., … Kurz, W. A. (2021). Natural climate solutions for Canada. *Science Advances, 7*(23), eabd6034. https://doi.org/10.1126/sciadv.abd6034

Intergovernmental Panel on Climate Change. (2019). Summary for Policymakers. In: *Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey,

S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

Qualman, D. (2019). *Tackling the farm crisis and the climate crisis: A transformative strategy for Canadian farms and food systems.* National Farmers Union. https://www.nfu.ca/wp-content/uploads/2019/12/Tackling-the-Farm-Crisis-and-the-Climate-Crisis-Final-with-covers.pdf

5.0
Agricultural and Climate Change Policy in the 21st Century

Prairie agriculture trends are heavily influenced by government policy on agriculture, trade, and climate change. This section provides an overview of current policies at the federal, provincial, and local levels that provide an opportunity to mitigate and adapt to climate change.

Key messages:

- Compared to leading jurisdictions, Canadian agricultural policy lacks comprehensive policy signals and strategies to address climate change in the sector.
- The 2020 federal climate plan and 2021 federal budget increase the momentum on climate policy for agriculture that could be built upon and extended in the short term.
- While federal and provincial agri-environmental programming is generally limited in scope, there are examples of successful policies and programs, including regional and community initiatives, that have the potential to be scaled up for increased climate action across the sector.

5.1 Barriers to Effective Climate Change and Agricultural Policy

There are three significant barriers to creating effective agricultural climate change policies and programming in Canada and the Prairie provinces that bear mentioning here.

First, there is no concrete national target for emissions reductions across the entire sector, unlike leading countries such as France, Germany, Ireland, New Zealand, and others (Henderson et al., 2020). Targets are also lacking at the provincial level. In the absence of high-level policy signals, there is little clarity for producers, communities, and industry on where the agricultural sector must go.

Second, the efficacy of current agri-environmental programming is not clear due to a lack of program evaluation and transparency on environmental indicators and low funding availability. The Office of the Auditor General (OAG, 2008, 2017, 2018, 2019) has repeatedly found that the federal government has not reported on key agri-environmental indicators, including progress on government targets.[20] The availability of agri-environmental programming varies by province, with some provinces providing more accessible support than others.

[20] For example, the OAG (2018, 2019) found that AAFC has not conducted adequate assessments on the sustainability impacts of Environmental Farm Plans and on goals outlined in the Federal Sustainable Development Strategy. The OAG did a more comprehensive study on agri-environmental programming in 2008. At that time, they found that AAFC did "not know to what extent its environmental programs have improved the environment," that "senior management cannot be certain whether programs are achieving their intended results and where improvements are needed," and that the department "lacks sufficient data to demonstrate that action at the farm level has led to positive environmental change" (OAG, 2008).

Third, there is a lack of comprehensive planning and policy strategy on agriculture and climate change between federal government departments and between different levels of government. Those countries leading on this issue have wide-reaching and comprehensive strategies to achieve their agricultural targets for emissions reduction, areas of land under sustainable production, and livelihood goals, rather than one-off programs (Henderson et al., 2020).[21] In Canada, this lack of coordination has resulted in few concrete actions by farmers to address climate change, since they are facing different regulatory and support systems.

5.2 Federal Policy

Under the Canadian Constitution, agricultural policy is an area of shared jurisdiction between the federal and provincial governments. Generally, programs and policy frameworks are developed and negotiated by the federal government in conjunction with the provinces (currently the CAP—see Section 5.2.2). The federal government primarily has power through its constitutional responsibility for trade and spending (including through managing equalization payments between provinces) (van Kooten, 2018). Provinces retain a relatively high amount of control over developing their own agricultural policies and programs, and negotiate with the federal government regarding how funds are allocated to their particular interests (van Kooten, 2018). As a result, provincial policy on agriculture can vary substantially by province, with a mix of provincially funded programs, federally funded programs, and cost-shared programs.[22] A full table of relevant policies and programs can be seen in Annex 1. The issue of shared jurisdiction poses significant challenges to ensuring comprehensive climate-compatible policies and programs.

Federal agricultural policy has yet to fully mainstream climate change considerations. Progress on climate change by AAFC has been slow and only recently addressed: as recently as 2017, the department was identified as not having fully assessed climate change risks as part of departmental responsibilities (OAG, 2017). The tide appears to be turning with recent federal announcements for climate solutions in agriculture (see Section 5.2.3), but more policy support is needed. For example, investment in research and development in agriculture is heavily focused on conventional agriculture, and very little is spent on research in organic agriculture, despite its potential to influence sustainable practices across the sector more generally (Standing Committee on Agriculture and Agri-Food, 2018).

The current emphasis on resiliency and sustainability in AAFC programming occurs within the context of increasing growth and exports in the sector, rather than framing it as a necessity in order to address the climate and biodiversity crises and mitigate farm- and community-level social and economic impacts. The government's commitment to introducing a "climate lens to integrate climate considerations throughout government decision-making"

---

21 See Henderson et al. (2020) for a full summary of country-level actions on climate change and agriculture.

22 In addition, many agricultural programs operate on a cost-share basis where producers are responsible for a portion of project costs.

(ECCC, 2020c, p. 59) will hopefully increase momentum to better align agricultural programs and policies with Canada's climate change commitments.

5.2.1 Domestic Policy in the Context of Trade and International Commitments

Canada's international commitments on sustainability will require concerted and ramped-up efforts, including from the agricultural sector. Many of Canada's sustainability policies and commitments are in response to international treaties and agreements on climate change, biodiversity, and other sustainability issues; however, we are behind in meeting many of these promises. While recent policies give some hope for Canada's climate ambition, historically, Canada has not been on track to meet its emissions reduction targets under the Paris Agreement (United Nations Environment Programme, 2020). Canada is also lagging in achieving the Aichi Biodiversity Targets under the United Nations Convention on Biological Diversity (CBD),[23] which include eliminating harmful subsidies and sustainably managing agricultural lands by 2020 (CBD, 2020b). Canada has also outlined goals and progress for achieving the 2030 Agenda for Sustainable Development (including the Sustainable Development Goals), including implementing "comprehensive strategies and programming that will support the sustainable production of agriculture within Canada" (Government of Canada, 2018). However, they have not taken significant steps to achieve this target.

The federal government has established targets on trade and economic growth that compete somewhat with an ambitious environmental agenda. In 2019, the federal government released its Food Policy for Canada, a cross-cutting, evergreen policy that for the first time links food access policy issues with food system issues.[24] One of its defined outcomes is "sustainable food practices," which highlights improving environmental performance and climate resilience across the food value chain, including emissions reductions (AAFC, 2019). The current iteration of the policy lacks detail on what this means for the agricultural sector, and short-term goals include continued focus on supporting export growth. This tension between increasing exports while decreasing environmental impacts can also be seen in the 2016–2017 reports by the Advisory Council on Economic Growth (the *Barton Report*),[25] Canada's Federal Sustainable Development Strategy 2019–2022, and the 2016 and 2020 climate plans (the *Pan-Canadian Framework on Climate Change and A Healthy Environment and a Healthy Economy*).

[23] One of Canada's targets under the CBD is: "By 2020, agricultural working landscapes provide a stable or improved level of biodiversity and habitat capacity"(CBD, 2020a).

[24] The Food Policy for Canada identifies Canada's vision as: "All people in Canada are able to access a sufficient amount of safe, nutritious, and culturally diverse food. Canada's food system is resilient and innovative, sustains our environment and supports our economy" (Agriculture and Agri-Food Canada, 2019).

[25] The *Barton Report* targeted substantially increasing Canada's share of agrifood and global agricultural exports in order to become the second-largest agricultural exporter in the world, worth an extra USD 30 billion in exports per year (Advisory Council on Economic Growth, 2017).

5.2.2 The Canadian Agricultural Partnership

The CAP is the main framework through which federal funds flow to the agricultural sector. It includes CAD 3 billion in investments over 5 years, from 2018 to 2023 (ECCC, 2019a). Federal-provincial negotiations occur every 5 years. The CAP includes a variety of components, including federally funded programs, cost-shared programs (on a 60:40 basis) delivered by provinces, and a suite of business risk management (BRM) programs. The CAP generally focuses more on growth and technology and less on sustainability (Wilson, 2017). There is some mention of resiliency and assisting farmers in adapting to climate change but no mention of reducing GHG emissions in agriculture (AAFC, 2020b).

5.2.2.1 BRM PROGRAMS

The CAP's BRM programs are designed to assist producers in managing the inherent and substantial risks in the sector. In general, these programs provide financial support, cash flow, and insurance to manage changes in market circumstances and the impacts of natural hazards and disasters. Unfortunately, current BRM programming may actually be providing incentives for less climate-friendly production methods. For example, some programs have been demonstrated to favour mono-production models, which are at higher risk of climate-related disasters while lacking accessibility for lower-input or organic producers whose diversification make them less risky (National Farmers Union, 2020; Organic Council, 2017).

5.2.2.2 ENVIRONMENTAL FARM PLANS

The Environmental Farm Plan (EFP) program is offered across Canada but differs from region to region, with some provinces delivering the program in partnership with a third-party organization. For example, in Alberta, the program is delivered through the Agricultural Research and Extension Council of Alberta, while in Manitoba, the program is delivered through Keystone Agricultural Producers. The goal of the program is to do a whole-farm assessment to identify actions to improve sustainable practices and farm operations (Government of Manitoba, n.d.). Completion of an EFP is also a prerequisite to access certain grants under the CAP.

Despite the lack of a comprehensive program evaluation, EFPs have been cited as extremely effective in improving sustainability and adaptability on individual farms (Standing Committee on Agriculture and Agri-Food, 2018). Yet uptake of the EFP program has been low on the Prairies compared to other provinces. Nearly two thirds of farms on the Prairies do not have an EFP, compared to only 19% in Quebec (Statistics Canada, 2019a). Uptake also varies by farm type: only 30% of beef producers have an EFP, compared to 80% of pig producers and 81% of dairy producers (Statistics Canada, 2019b).[26] The low uptake on the Prairies is cause for concern. More evaluation is needed to understand barriers for program uptake, including a lack of

[26] EFPs can also be a useful tool for industry-led cross-compliance. Notably, the Potato Growers of Alberta was the first industry association to require completion of an EFP for membership (Agricultural Research and Extension Council of Alberta, 2020).

standardization across provinces and implications for the adoption of BMP funding that requires completion of the program.

5.2.3 Federal Climate Policies and Programs

Existing and evolving federal climate policies and programs are highly relevant for the agriculture sector. Canada's updated nationally determined contribution under the Paris Agreement affirms Canada's commitment to reach net-zero emissions by 2050 and increases the 2030 target to 40%–45% reductions compared to 2005 levels (ECCC, 2021). Although the 2016 Pan-Canadian Framework on Climate Change and Clean Growth had little mention of agriculture (ECCC, 2016), the updated 2020 climate plan introduces a new focus on the sector. It includes a commitment to work with provinces, a target to reduce fertilizer use-related emissions by 30% below 2020 levels (no end date provided), and a proposal to advance the production of feedstocks for biofuels (ECCC, 2020c). Funding commitments announced in the climate plan and 2021 federal budget include CAD 165.7 million over 7 years for an Agricultural Clean Technology Program (including CAD 10 million for clean energy adoption); CAD 200 million over 2 years for improved nitrogen management, cover cropping, and rotational grazing under the Agricultural Climate Solutions program's On-Farm Climate Action Fund; and CAD 185 million for the Agricultural Climate Solutions Living Lab program (Department of Finance, 2021; ECCC, 2020c).

These amounts signal a shift in federal policy but are nonetheless modest compared to what will be needed to properly transition the agricultural sector.

5.2.3.1 CARBON PRICING

The federal carbon pricing system was first introduced in 2018 and is one of the government's primary policy tools for addressing climate change. Under the 2020 climate plan, the fuel charge is now slated to increase by CAD 15/tonne each year after 2022 to reach CAD 170/tonne by 2030 (ECCC, 2020c), a move that was widely lauded by the international community (United Nations Framework Convention on Climate Change [UNFCCC], 2020). The fuel charge portion of the federal system applies in provinces that do not have equivalent provincial systems.

The federal fuel charge currently exempts on-farm fuel use (Canada Revenue Agency, 2019). There are similar policies in subnational jurisdictions that exempt on-farm fuel use and certain agricultural activities from carbon pricing and fuel taxes. These exemptions essentially function as fossil fuel subsidies as they artificially lower the costs of these fuels (Corkal et al., 2020; OECD, 2020). In 2021, the House of Commons also adopted a bill to exempt additional farm fuels such as propane and natural gas (at the time of writing, Bill C-206 has yet to receive royal assent by the Senate) (Parliament of Canada, 2021).

5.2.3.2 CARBON OFFSETS

Canada is currently developing a federal GHG emission offset program and is developing offset protocols separately from the broader offset regulations. The government has proposed to identify opportunities in agriculture and is examining enhanced soil organic carbon as part of its initial protocol development (ECCC, 2020c). Offsets could provide economic benefits for farmers while incentivizing emissions reductions, although specific opportunities for the sector on the Prairies are yet unclear. Some producer organizations have been advocating for recognition of certain agricultural practices under the program, such as 4R nutrient management and habitat protection projects, but it is yet unclear what type of protocols will be eligible under the final program (Binkley, 2020; Milton, 2020).

However, there are substantial risks associated with certain types of offset protocols regarding issues such as additionality and permanence[27] (for example, conservation cropping protocols have been particularly controversial). It will not be possible to achieve adequate emissions reductions and resiliency with carbon offsets and market-based measures alone. For example, in many cases, carbon markets have not led to overall net, long-term emissions reductions in agriculture due to challenges with leakage and additionality (Institute for Agriculture and Trade Policy & National Family Farm Coalition, 2020).

Regardless, the development of a robust offset market will take time, possibly years, and prices available for offset credits will vary depending on several risks and factors. Risks and opportunities for carbon offsets will be more thoroughly explored in the second paper of this series.

5.2.3.3 ADAPTATION AND RESILIENCY PROGRAMS

In its updated climate plan, the federal government has also committed to advancing a National Adaptation Strategy, which is intended to inform policy direction and help measure progress, in collaboration with subnational governments, Indigenous Peoples, and other partners (ECCC, 2020c).

Several adaptation and resiliency-focused programs outside of AAFC have benefits for rural communities, including agricultural producers, such as:

- Infrastructure Canada's Disaster Mitigation and Adaptation Fund supports large-scale infrastructure to address vulnerabilities to extreme events (Government of Canada, 2020b). Additional funding of CAD 1.4 billion over 12 years was announced for this fund in the 2021 budget (Department of Finance, 2021).
- Natural Resources Canada's Building Regional Adaptation Capacity and Expertise (BRACE), 2017–2022 program provides funding to subnational governments and organizations for priorities that increase capacity to implement adaptation measures. Of current projects on the Prairies, only one has explicit links to agricultural resilience (Water Management Capacity Building to Achieve Climate Resilience run by the Saskatchewan Water Security Agency) (Natural Resources Canada, 2018).

[27] "Additionality" is a critical feature of offset credits and requires that a project's emission reduction activities would not have happened without an offset buyer. "Permanence" simply means that emission reductions through a given project cannot be reversed (i.e., emitted back into the atmosphere).

- The Canadian Centre for Climate Services provides access to climate data to inform decision making and has established a regional hub for the Prairies, ClimateWest (Government of Canada, 2021).
- The proposed Canada Water Agency is under development, which will include identifying ways to support more resilient irrigation infrastructure and water management (Department of Finance, 2021).
- There are also federal funds available through the Federation of Canadian Municipalities for climate mitigation and adaptation (the Green Municipal Fund), the Standards to Support Resilience in Infrastructure Program, which helps communities plan climate-resilient infrastructure, and other programs focused on flood and wildfire preparedness.

Box 2. Flood management and agricultural sustainability

Integrated flood risk governance is a critical area for governments to navigate in the era of climate change (Hurlbert, 2018). Flood-related policies and programs are not necessarily agriculture-specific, yet they have major implications for agricultural producers and communities. For example, the federal government's Disaster Mitigation and Adaptation Fund invests in projects that reduce the socio-economic, environmental, and cultural impacts of natural hazards and extreme weather events (Government of Canada, 2020b).

Numerous programs, policy frameworks, and planning documents also exist at the provincial level. For example, Saskatchewan recently completed a Flood and Natural Hazard Risk Assessment in an attempt to support provincial and local decision-makers to manage risk (Wittrock et al., 2018). Watershed-based organizations also have some institutional capacity and mechanisms for local climate change adaptation planning and exist in all three Prairie provinces (Sauchyn et al., 2020). Research on flood policy instruments in Saskatchewan and Alberta shows that there is progress needed on community-based flood preparedness and management and on ensuring government flood planning adequately integrates climate change considerations (Hurlbert, 2018).

5.3 Provincial Policies

No Prairie province has identified emissions reduction targets for 2030 and 2050 (let alone interim targets), and when it comes to robust climate policy, these provinces are behind other Canadian provinces and territories (Dusyk et al., 2021). Provincial governments on the Prairies generally have not targeted the agricultural sector for emissions reductions, and while programs to incent more sustainable and resilient practices exist, they are limited in scope and accessibility. Each province has some examples of positive and effective programming to promote climate-resilient practices, but overall, climate change mitigation and adaptation have not been fully mainstreamed across agricultural policies and programs. A significant challenge for producers on the Prairies is the general lack of extension services (see Section 2.4).

5.3.1 Alberta

Alberta has not published an updated climate change plan since its 2008 strategy, which is mitigation-focused (Government of Alberta, 2008). Meanwhile, the province outlined plans for its agricultural sector in its Agriculture and Forestry Business plan, the latest of which covers 2020 to 2023 (Government of Alberta, 2020a). Generally, the plan focuses on reducing regulatory burdens (including for animal and crop disease control policies), promoting trade, and encouraging innovation and economic growth. A major component of the plan is "Responsible Resource Management," which includes promoting environmental stewardship practices and supporting producers to better manage water supplies. Alberta has also had a carbon offset system in place for several years. A number of offset protocols can potentially be used by farmers, including for livestock feed, biofuel production and use, manure management, nitrous oxide emission reductions, and conservation cropping (Government of Alberta, 2020b). The latter protocol expires in 2021, based on an estimated 20-year saturation point for stored carbon under conservation cropping practices.

Alberta's CAP funding includes a number of programs focused on better water management and water supply as well as the Environmental Stewardship and Climate Change funding stream to support the adoption of BMPs (Government of Alberta, 2020c). For the latter, producers must have a completed EFP to apply. Unfortunately, Alberta recently moved to cut nearly half of Alberta Agriculture employees (277 positions) (Oosterhuis, 2020). The government also recently created the Results Driven Agriculture Research non-profit organization, an arms-length centre focused on agricultural research with a focus on growth and competitiveness (Government of Alberta, 2020d). The implications of this change to producer access to extension services and information and support for the adoption of sustainable agricultural practices are yet unclear.

5.3.2 Saskatchewan

Saskatchewan's policy focus for agriculture is heavily focused on market growth, and its provincial and CAP programming reflect this. *Saskatchewan's Growth Plan*, released in April 2020, outlines agricultural targets to 2030 including:

- Growing crop production to 45 million tonnes (from 35.4 million) and the livestock cash receipt to CAD 3 billion (including through increased intensive livestock operations)
- Expansion of irrigation
- Increase local processing of canola and pulses (Government of Saskatchewan, 2020).

The *Growth Plan* has very little focus on sustainability in the agricultural sector.

Saskatchewan's climate change strategy, *Prairie Resilience*, takes a resilience- and adaptation-focused approach to climate change that was well-received by various farm groups in the province

(RealAgriculture, 2017). However, the plan generally falls short of providing direction and targets for emissions reductions, which has led to criticism from environmental experts (Mandryk, 2019; Saskatchewan Environmental Society, 2019; White-Crumney, 2019). The plan identifies the positive role that the agricultural sector can play through approaches such as low-tillage practices but otherwise lists few specific actions for emissions reductions in the sector.

Under the CAP, Saskatchewan does have a suite of cost-share initiatives focused on "Environmental Sustainability and Climate Change" (Government of Saskatchewan, n.d.). In general, these programs aim to improve on-farm practices to increase agricultural resiliency, but emissions reductions are not a major focus. A number of these programs are focused on water management, including the Irrigation Program, Farm and Ranch Water Infrastructure Program (FRWIP), and Agri Environmental Technical Services (which partners with watershed stewardship associations). As with similar programs elsewhere, Saskatchewan's Farm Stewardship Program (FSP), which provides funding to producers to implement BMPs, requires the completion of an EFP. The FSP has three priority areas (water quality, climate change, and biodiversity) that reflect an evolving approach to agricultural sustainability.

Although not explicitly designed for climate change adaptation, programs such as the FSP and FRWIP have helped producers build resilience to climate variability and reduce socio-economic impacts of drought. This has occurred at both the individual farm and regional levels. Hurlbert & Pittman (2014) found that Agri-Environmental Group Plans created under the previous iteration of the FSP program helped with regional watershed and environmental planning, beyond what individual EFPs can achieve. However, these programs have shifted over time. The FRWIP has adopted a more passive adaptive management approach with a provincial rather than regional focus and is now less structured and responsive (Hurlbert & Pittman, 2014). Research has illustrated barriers for producers and rural communities in accessing the program, such as inconsistent funding, relatively high cost-share requirements, and limited human resource capacity for program implementation.

5.3.3 Manitoba

Manitoba's approach to climate change policy is outlined in its 2017 *Made-In-Manitoba Green Plan*. Manitoba was also the first province to pass climate accountability legislation (the Climate and Green Plan Implementation Act, 2018). Unfortunately, this legislation does not outline a clear pathway for emissions reductions or specific long-term targets (Canadian Institute for Climate Choices, 2020). The 2017 plan looks at agriculture in terms of potential for carbon sequestration but does not outline emissions reduction targets (Manitoba Sustainable Development, 2017)

Manitoba also released a Protein Strategy in 2019, which focuses on substantially increasing both animal and crop protein sources. The strategy lists targets of increasing animal processing and production by 35%, reducing carbon intensity per kilogram produced by 15%, and increasing productivity of Crown land and private grasslands by 15% (Government of Manitoba, 2019a).

The majority of Manitoba's agricultural programming falls under the umbrella of Ag Action Manitoba, cost-shared through CAP. Particularly relevant to climate change mitigation and adaptation is available funding for producers to adopt environmental BMPs, based on actions recommended in a given farm's EFPs. The list of eligible BMPs is extensive, and applications are rated based on various criteria, including an Environmental Benefit Assessment Index (Government of Manitoba, 2020b).

Manitoba also has a suite of programming related to ecological goods and services (EGS). For example, the Ag Action Manitoba EGS program provides support to watershed districts, which work with producers on implementing sustainable practices (Government of Manitoba, 2020a). There are numerous provincially funded programs on EGS as well, including a Riparian Tax Credit and Protected Areas Initiative, as well an EGS Initiative Working Group, whose focus is on developing agricultural policies that provide environmental, social, and economic benefits (Government of Manitoba, 2020c). The Growing Outcomes in Watersheds program, a CAD 5.2 million program to pay for the enhancement of EGS on private lands based on the ALUS model, was introduced in 2019 (see Section 5.4.1) (Government of Manitoba, 2019b). Manitoba also has the Conservation Trust, which was established in 2018 as part of the provincial climate plan to fund conservation and natural infrastructure activities (Manitoba Habitat Heritage Corporation, 2021).

5.4 Community Responses

In addition to federal and provincial approaches, a number of innovative initiatives to address climate change impacts and opportunities in agriculture have emerged at the community level. We highlight three examples below that illustrate the potential for farmer-focused programming to promote climate-friendly agricultural practices. See Table A5 for details of other examples.

5.4.1 ALUS: Promoting ecosystem services on agricultural lands

The ALUS model has had considerable success in Canada in promoting the restoration and conservation of EGS on agricultural lands. ALUS works in tandem with local stakeholders and agricultural organizations and provides direct payments to producers for eligible projects, including wetland restoration, wind and riparian buffers, sustainable drainage systems, reforestation, and pollinator habitat creations (ALUS, 2021). The non-profit organization is funded through a number of sources, including federal and provincial governments, individuals and individual benefactors, and foundations. Overall, ALUS is active in six provinces and has worked with over 900 producers and 31 communities, representing over CAD 10 million in investments and over 32,000 acres of land (ALUS, 2021). On the Prairies, ALUS operates three projects in Saskatchewan, two in Manitoba, and 15 in Alberta to support projects to improve riparian areas, control invasive weeds, and convert cropland to native prairie grasslands, among other activities.

5.4.2 Local Organizations Promoting Climate-Compatible Agricultural Practices

There are several small-scale organizations and initiatives across the Prairies doing important work directly with producers to promote sustainable agricultural practices. The producer-based Saskatchewan Soil Conservation Association (SSCA) is one such organization that has existed for over 30 years to advance conservation agriculture in the province. With around 300 producer members, the organization has provided support to farmers by developing extension materials and operating technology transfer programs, connecting members with each other to support peer learning, participating in research projects, and running an annual soil conservation conference (SSCA, n.d.-b). The SSCA played a significant role in promoting and facilitating the adoption of low-till agriculture in the province (Standing Committee on Agriculture and Agri-Food, 2018; SSCA, n.d.-a), although today it is a smaller organization no longer doing extension work at a province-wide scale.

A more recent initiative that presents an excellent model is Rural Routes to Climate Solutions (RR2SC). Based in Alberta, the program works directly with producers and rural communities to promote climate-friendly on-farm practices through educational opportunities (workshops, field days, podcasts, and blogs), many of which are free (Rural Routes to Climate Solutions, 2020). The organization is also promoting on-farm renewable energy projects and has started a Solar Lab to assist communities in developing community-owned solar projects by connecting them with technical experts and training opportunities.

Further Reading

“Sustainable Food” chapter in Environment and Climate Change Canada. (2019). *Achieving a sustainable future: A federal sustainable development strategy for Canada 2019 to 2022.* http://fsds-sfdd.ca/downloads/FSDS_2019-2022.pdf

Environment and Climate Change Canada. (2020c). *A healthy environment and a healthy economy.* https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

Hurlbert, M., & Pittman, J. (2014). Exploring adaptive management in environmental farm programs in Saskatchewan, Canada. *Journal of Natural Resources Policy Research, 6*(2–3), 195–212. https://doi.org/10.1080/19390459.2014.915131

Farmers for Climate Solutions Task Force. (2021). *A down payment for a resilient and low-GHG farm future: A $300 million plan to reduce agricultural GHGs by 10 Megatonnes and lay the groundwork for widespread adoption of climate-friendly farming in APF 2023.* https://static1.squarespace.com/static/5dc5869672cac01e07a8d14d/t/603cf540ca355d0ac5009619/1614607684484/FCS_BudgetRecommendation2021.pdf

6.0 Conclusions and Recommendations

While anthropogenic climate change presents an enormous challenge, there are several ways that producers, communities, non-governmental organizations, producer associations, and policy-makers can act to mitigate GHG emissions and adapt to new contexts. Climate change will change the way Prairie producers run their operations, as well as the ways they understand risk and decide how to reduce risks to themselves and their operations. This section summarizes our findings about changes and impacts to on-farm practices. We then identify opportunities to enable climate-friendly on-farm practices and make recommendations for how policies can support long-term change in the sector by considering the broader cultural and policy shifts that are necessary. We also suggest ways to ensure that policies are holistic and flexible to support producers through the significant adaptation and mitigation processes that are required now and into the future. Further details on specific policy recommendations will be included in the second report in this series.

6.1 Key Findings

6.1.1 Emissions from Prairie Agriculture Are Significant and Increasing

Despite the adoption of practices, such as no-till by many farmers, agricultural emissions on the Prairies continue to be high. Emissions from nitrous oxide and methane, stemming primarily from fertilizer practices and animal production, are particularly worrying given their high global warming potential.

Yet, in the most ambitious scenario outlined in ECCC's 2019 *Fourth Biennial Report on Climate Change* to the UNFCCC, agricultural emissions are projected to grow, even as emissions from most other sectors decrease. Emissions are projected to increase from 72 Mt CO_2e in 2017 to 74 Mt CO_2e in 2030, ending 4 Mt CO_2e higher than 2005 levels (ECCC, 2019b). These increases may not seem particularly high—they amount to less than 6% over 25 years—but they were projected at a time when Canada was pledging an economy-wide reduction of GHG emissions of 30% over the same period. Based on current trends, fertilizer-related emissions will likely increase, while emissions in livestock may decrease due to smaller cattle herds. On-farm fuel use is expected to stay consistent (ECCC, 2019b).

The agricultural sector has an important role to play in reducing emissions to limit global warming and its impacts. This also presents an opportunity, as many of the actions taken to reduce emissions ultimately have benefits for farmer incomes, increased resiliency, biodiversity, and more.

6.1.2 Climate Change-Related Impacts Are Slated to Rise, Increasing Vulnerability and Risk for Prairie Producers

A changing climate means impacts to Prairie producers: crop yields and livestock production will be affected by changing patterns such as general warming and changes in precipitation, and communities will grapple with more or worsened extreme events such as floods, heat waves, droughts, and wildfires. In response to climate change impacts and policy responses by Canada's trading partners, market trends are also slated to shift. The resulting economic and political changes could substantially influence Prairie producers' incomes as demands and prices for products shift. The ability of producers and their surrounding communities to weather direct and indirect impacts from climate change and policy responses will depend heavily on whether risk can be effectively minimized through both on-farm actions and enabling policies and programs that support individual and collective resilience.

Adaptation and mitigation are closely related. The effectiveness of mitigation actions by Prairie producers and by governments and sectors in Canada and around the world will have major impacts on the levels of future warming that producers and communities will have to grapple with (Warren & Lulham, 2021).

6.1.3 A Lack of Policy Action and Sufficient Investment to Address Sectoral Emissions Impacts Producers

The Government of Canada has not yet published a fully detailed pathway for the agricultural sector to contribute to the federal target of net-zero by 2050. There is no government-endorsed sectoral target nor sufficient investments or policy support to ambitiously reduce emissions across the agricultural sector. This lack of attention to what is possible to achieve in the sector is also the case at the provincial level.

In comparison, other jurisdictions have identified ambitious targets for the sector alongside substantial financial commitments to support farmers, recognizing that emissions reductions and increased producer resilience go hand in hand (Farmers for Climate Solutions, 2021). For example, the EU Climate Target Plan identifies the potential for climate neutrality in agriculture, and Ireland's Ag-Climatise roadmap outlines a goal to achieve net-zero in the sector by 2050, with many supporting policies and programs to improve farmer livelihoods (European Commission, 2020; Government of Ireland, 2020). The 2020 Canadian federal climate plan and 2021 budget introduced several positive new measures for climate action in agriculture, and the government stated its commitment to work with producers. That said, federal and provincial investments and supportive policy environments are still far from what is needed. Ultimately, supporting producers to manage climate change will help ensure the future viability of producers and their livelihoods while enabling progress on Canada's climate goals.

Addressing climate change and other environmental concerns will require significant financial investments from governments and industry. These investments should be seen as a down payment to ensure a prosperous future for producers while helping to reduce climate change and its related impacts and costs. Here again, Canada is behind other jurisdictions. Pre-pandemic, the EU was spending over 73 times more than Canada on agri-environmental programs on a per-acre basis, while the United States was spending 13 times more (Farmers for Climate Solutions Task Force, 2021). Meanwhile, the Canadian federal government spends less on climate change mitigation and adaptation in agriculture than in other sectors, such as transportation and energy (Farmers for Climate Solutions Task Force, 2021).

6.1.4 Ensuring Lasting Change Will Require a Shift in the Culture of Agriculture

By working with farmers, farm communities, and all levels of government and across departments, **policy-makers can ensure that climate action becomes part of the culture of agriculture.** However, more than just agriculture departments need to be part of these conversations. Departments of natural resources, health, community development, rural planning, transportation, and finance all have important parts to play. Beyond government representatives, policy development will also require ongoing consultations and collaboration with producers and communities.

As climate change is already occurring and will continue long into the future, it is critical that policy-makers act to increase the resilience of producers and farming communities and to support a culture of farmers taking action to mitigate and adapt. Understanding the history of the Canadian Prairies helps contextualize where we are today and the foundation that the agricultural system has been built on. This includes understanding the ongoing challenges presented by settler colonialism and ongoing tensions over land rights in this country. Many of the vulnerabilities of farming and rural communities have their origins in this history, but this is also where they have their strengths. Working with Indigenous communities to address climate change provides an opportunity to reconcile our collective histories and work toward a healthier and more sustainable future.

Researchers have coined the term “good farmer” to discuss how cultural norms around farming attitudes, behaviours, and practices develop over time and how, therefore, these can be shifted by policies that support sustainability (Burton et al., 2020). For example, most of the policies on the Prairies support the idea of a “good farmer” as a farmer who is productive, exports food, has weed-free crops, and acts individually to maximize their own profits. In the 1930s and 1940s, when the PFRA supported farmers to take actions to manage the health of their farm ecosystems and collective actions by farming and rural communities helped establish schools, banks, and telephone networks on the Prairies, “good” farmers were still productive exporters, but they were also stewards of the land and community builders. They planted shelterbelts and built dugouts, both of which supported biodiversity; ran mixed farms to minimize risk; and acted collectively to market their grain through processes such as the Canadian Wheat Board (Atkinson & McCrorie

2003, Marchildon et al., 2008). Understanding the implicit cultural values that policy changes support can help policy-makers understand how to shift farming behaviour.[28]

6.2 Changing On-Farm Practices

Producers are at the frontlines of climate change adaptation and mitigation. The following is a list of practices that draw on agroecological principles that will help producers, whether they are crop or livestock producers, reduce emissions and build resilience in the face of climate change. Some of the changes listed below will be relatively simple for producers to enact, while others will require time to build knowledge and skills. By investing in these changes now, we can help secure the future of agricultural production, and of farming communities, on the Prairies.

- **Reduce chemical use**, including both pesticides and synthetic fertilizers, by reducing application rates, using the 4Rs, and exploring opportunities from integrated pest management practices.
- **Better crop rotations**, including the use of perennial crops, cover cropping, and intercropping, since monocultures are more vulnerable to pest problems and are more likely to result in poor soil conditions and therefore need more chemicals.
- **Rotational and mob grazing to improve pastures**, which can sequester more carbon, result in less erosion, and support greater biodiversity.
- **Integrate crop and livestock rotations:** grazing livestock leave behind manure that can be integrated into the next crop, reducing the need for manure management practices and for synthetic fertilizers.
- **Better livestock practices**, including manure management, but also feed practices and strategies to maximize herd health while reducing enteric fermentation.
- **Lower operational energy-related carbon footprints**, including fuel management, fuel switching, energy efficiency, and renewable energy generation.
- **Improve land stewardship practices**, including shelterbelts and conservation of forests and wetlands, to preserve biodiversity and carbon-rich landscapes.
- **Adopt adaptation actions**, such as improving on-farm infrastructure, changing planting practices, strengthening water management, practising mixed farming, and considering climate data in farm planning.

Prairie producers need support to transition to sustainable practices while ensuring revenues are maintained and livelihoods supported. In the long run, the adoption of these approaches will help

[28] For example, in Burton's original research (2004), he looked at how farmers' attitudes around weed-free fields influenced whether they were willing to adopt organic agriculture. Farmers were concerned that since organic practices may result in weeds in their fields, this may lower their esteem among their peers who continue to value fields that show little to no presence of weeds.

ensure producers are fully equipped to manage climate change while supporting the stability of the Prairie agricultural sector.

6.3 Enabling Short-Term Support and Systemic Change

This section explores the types of supports that would be the most beneficial in both the short and long terms, both to help shift on-farm practices and to create broader enabling environments so that Prairie producers and their communities can confront climate change. The International Institute for Sustainable Development's second paper in this series will examine in more detail the specific policy and program opportunities to support Prairie producers to act.

Industry, non-governmental organizations, and local, provincial, and federal governments all have a role to play in achieving needed shifts. Below are some of the ways these bodies can positively support producers in building resilience and increasing climate action.

6.3.1 Actions to Support Producers

6.3.1.1 FEDERAL AND PROVINCIAL GOVERNMENTS

There are many ways that governments can support producers to make positive changes to on-farm practices while supporting farmer incomes. Since agriculture is a shared federal-provincial responsibility, there is a significant role for the CAP to mainstream climate action, with the next agreement set for 2023.

Clear and ambitious emissions reduction targets for the sector from federal and provincial governments are also needed, which will send important policy signals to the sector. Existing insurance and funding programs can be shifted or built upon to encourage climate-friendly practices by producers while discouraging harmful ones. Provincial governments should strive to be leaders on climate action in agriculture in order to support the viability of the sector, as BC has already started doing (Box 3).

- **Reinstate funding for public extension services and research** with a renewed focus on agroecological practices and climate resilience within both government and universities. This can inform policy development as well as emissions reduction potential. For example, the Government of France commissioned a study on the carbon storage potential of soils (the 4 per 1000 Initiative for Food Security and Climate) that then informed the national Low Carbon Strategy and its integration of climate-friendly agricultural practices (Institut national de la recherche agronomique, 2019).
- **Introduce crop insurance discounts for BMPs** to draw clear linkages between improved practices and reduced climate risk by rewarding positive actions. The Green Budget Coalition (GBC), a coalition of Canada's leading nature conservation and environmental non-profits, recommends a short-term target of 10% of BRM investment for agroecological practices (GBC, 2021).

- **Establish incentives for improved livestock practices**, including grazing BMPs, manure management, and reduction of enteric fermentation. The Farmers for Climate Solutions Task Force estimates that a CAD 25 million investment to normalize rotational grazing would result in savings of 302 kt CO_2e in the short term (Farmers for Climate Solutions, 2021).
- **Facilitate payment for ecosystem services and nature-based solutions:** Keeping shelterbelts, woodlots, and wetlands supports carbon sequestration and improves soil and water quality.
- **Improve and establish programs to support greening on-farm energy use:** programs for energy retrofits, programs for green energy generation, and stricter regulations on emissions for farm equipment. The Farmers for Climate Solutions Task Force outlines six pilot programs that could be implemented in the short term with CAD 8 million in investments to improve on-farm vehicle efficiency and energy use (Farmers for Climate Solutions, 2021).
- **Ensure robust criteria and processes for carbon offsets:** As government develops the federal GHG offset protocols, careful attention must be paid to ensure all protocols adequately consider issues around additionality and permanence. This includes proper measurement of captured carbon (for example, through soil sampling). Attention should be paid to other risks associated with carbon markets in agriculture, such as pollution and consolidation (Institute for Agriculture and Trade Policy & National Family Farm Coalition, 2020).
- **Identify and phase out harmful agricultural subsidies:** Canada has international commitments to phase out subsidies that incent polluting or environmentally harmful practices under the G20, the Sustainable Development Goals, and the Aichi Biodiversity Targets. The GBC recommends that Canada eliminate fossil fuel subsidies as well as subsidies from the CAP and BRM that cause environmental harm (GBC, 2021).
- **Ensure conditionalities in funding programs:** Government funding for agriculture should have robust and transparent financial, social, and environmental criteria to ensure that spending contributes to, and does not detract from, a sustainable agricultural transition. For example, any funding to industry should have strict conditions attached, including mandating company net-zero targets and plans (Corkal et al., 2020).

Box 3. Climate-focused agricultural programming in British Columbia

BC has chosen to invest CAP funding to promote several climate change-related initiatives. The BC approach provides an interesting model due to its focus on both regional and farm-level programming. The Ministry of Agriculture's Climate Action programs cover a suite of both climate change adaptation and mitigation initiatives, with dedicated ministry staff to support climate change action by the sector (BC Ministry of Agriculture, n.d.). The department has undertaken significant work to map out adaptation pathways for the sector as well as identify how on-farm practices can increase climate resilience on BC farms (BC Ministry of Agriculture, 2019; Government of British Columbia, n.d.,).

In 2008, BC created the Climate & Agriculture Initiative, which is funded through the CAP and administered by the BC Agricultural Research & Development Corporation and the Investment Agriculture Foundation of BC (Climate & Agriculture Initiative, 2021). This groundbreaking initiative included developing the 2010 Climate Change Action Plan for the sector, publishing a number of Adaptation Risk and Opportunity reports for key commodities, and now includes the delivery of two adaptation-focused programs (one producer focused; one regionally focused). The Climate & Agriculture Initiative also provides the sector with substantial informational resources on climate change through its website and engagement activities.

The government has also supported a number of Regional Adaptation Strategies, which act as foundational documents identifying key climate change impacts and response strategies to increase resilience (Government of British Columbia, n.d.). These strategies have been completed through collaborative processes between provincial agencies, agricultural organizations, municipal governments, and agricultural producers.

6.3.1.2 INDUSTRY

The agriculture industry includes equipment manufacturers, chemical and seed companies, processing facilities, marketing and retailers, and transportation. Producers will not be successful at becoming climate resilient without the support of these industries.

- **Design new equipment** for increased fuel efficiency and zero emissions on farms and for the transportation of products, as well as for supporting techniques like intercropping and supplements for cattle to reduce digestive methane.
- **Create a climate change labelling standard for producers** similar to organic standards that allows farmers to demonstrate their hard work and give consumers an opportunity to choose products that match their values, with three tiers to maintain affordability. Include business training opportunities for participating producers to support ongoing learning and communities of practice. For example, one proposed program is called Canada's Agri-Food Sustainability Index.

- **Support research and market development for sustainable food production** by educating consumers and building processing facilities and through collaboration with producers, governments, academia, and civil society organizations. For example, Verdient Foods in Saskatchewan supported the development of a pea protein processing facility and works with researchers to develop new farming and processing techniques for these nitrogen-fixing crops. General Mills (n.d.) has begun pilot programs for regenerative practices via technical assistance for oat producers in Saskatchewan, Manitoba, and North Dakota.
- **Set ambitious corporate targets and roadmaps for emissions reductions and sustainability.** Very few companies in Canada have committed to the ambition required for a 1.5°C warming target (Science Based Targets, 2021). Yet public-private sector collaboration is critical to mobilize the capital required to shift to net-zero emissions, and the number of companies with net-zero pledges worldwide is growing (Woynillowicz et al., 2021). Robust company-based targets and action plans will ensure businesses can adapt to a net-zero economy while creating an enabling environment for the producers they work with.

6.3.1.3 NON-GOVERNMENTAL ORGANIZATIONS AND PRODUCER ASSOCIATIONS

Non-governmental organizations and producer associations often work directly with producers to help advocate for their needs and support them.

- **Mentoring:** Scale up existing local and regional programs to compensate innovative and climate-resilient farmers for their leadership as trainers and mentors in their communities. This can support the adoption of BMPs.
- **Research and advocacy for sustainable transitions:** Many organizations are already working to advocate for support for climate action for producers (for example, advocacy by Farmers for Climate Solutions was critical to ensuring the federal government's recent investments). Yet, there is a significant opportunity for producer associations and non-governmental organizations of all types to make the case to government and the private sector to provide support and an enabling environment for producers to act.

6.3.2 Working with Indigenous Communities

Indigenous knowledge has the potential to support climate change mitigation and adaptation planning (Sauchyn et al., 2020), particularly on the Canadian Prairies. This knowledge is based on detailed local observations, both historical and current, of changes associated with climate and is more likely to include social elements than much of the current agricultural science (Sauchyn et al., 2020). As a result, Indigenous Peoples are accustomed to exploring the relationship between human activity and the environment. For example, Indigenous agriculture was often based on a subtle nurturing of naturally occurring cycles to promote larger harvests for communities of plants, such as manomin (so-called wild rice) or blueberries (Davidson-Hunt, 2003), but it also included the planting of root vegetables by nomadic communities on the fringes of the boreal forest in Saskatchewan (Massie, 2014). The knowledge of traditionally marginalized communities, like Indigenous Peoples, can provide insights for more effective and inclusive climate change adaptation (Sauchyn et al., 2020). In addition, socially equitable adaptation and mitigation policies that go beyond inclusion, in order to reduce the origins of vulnerability, have the potential to increase equality over time (Sauchyn et al., 2020).

It is imperative that non-Indigenous actors engage respectfully and work in partnership with Indigenous knowledge keepers. **Through all policies, including those to address climate change in agriculture, Canadian governments must uphold Indigenous rights, work to strengthen nation-to-nation relationships, and increase the adaptive capacity of Indigenous Peoples.**

Several opportunities exist to work with Indigenous communities, such as:

- **Land trusts** and conservation and rehabilitation of farmland and pastures, including pasture management of former PFRA lands.
- **On-reserve gardening and small-scale farming** that involve working with communities to build skills, knowledge, and economic opportunities.
- **Land Back efforts** with individual farmers and communities. For example, land agreements have been made between settlers in Laird, Saskatchewan, and the Young Chippewayans First Nation, whom they had displaced in 1879 (Polachic, 2017), and between the Esk'etemc band and a local rancher in the Cariboo area of British Columbia (Lamb-Yorski, 2017).

Box 4. Learning and recovering from COVID-19

While the 2020 COVID-19 pandemic challenged Canadians in new ways, it also opened new conversations about how food is produced and distributed in this country. More Canadians than ever grew their own food in 2020 and bought from local farmers because of concerns around food supply chains (Fawcett-Atkinson, 2020b. It is possible that this trend may continue, but even if it does not, it did provide an important learning opportunity for Canadians to learn more about growing food. Local food systems, including urban agriculture, community-supported agriculture boxes, farmer's markets, etc., not only shorten transportation distances and thus produce fewer GHG emissions, but they also provide an important point of contact between urban and rural people and have the potential to build networks of solidarity. These networks and communities of supportive urban eaters may become more important to farmers who are going "against the grain" and using growing methods that remain unorthodox among their neighbours. Many new farmers are interested in agroecological methods and are relying on their urban eaters to support them financially and morally for ongoing success (Laforge & Levkoe, 2018).

6.3.3 Developing a Food Policy for Canada With Climate Change as a Focus

Agricultural policy should be considered within the broader food policy of governments—which by necessity integrates multiple sectors and ministries. A significant opportunity for the future exists with the Food Policy for Canada. Although the policy is housed within AAFC, it is attempting to work with and across government departments for the first time. It also has an Advisory Council that will hopefully support the development of flexible and ongoing consultation with Canadians, including farmers, farmworkers, Indigenous communities, and citizens, while also limiting the influence of corporations in comparison to previous policy development approaches. As the Food Policy for Canada continues to be developed and implemented, integrating climate change mitigation and adaptation should be a priority across departments, in line with the federal government's commitment to implement a "climate lens" across all federal policy-making (ECCC, 2020b).

To support the work of the Food Policy for Canada and its council, comprehensive measures within and alongside it are required to transform Canadian agriculture. Policy-makers can act in the following areas:

- **Adapt the BRM, the CAP, and the next agricultural policy framework in 2023** to fully integrate environmental issues and build agroecology in Canada with adequate funding; enable and incentivize best practices and implement collaborative solutions for climate change and biodiversity.
- **Improve monitoring and evaluation** to ensure that programs and supports remain effective and that social, economic, and environmental indicators and goals are measured and achieved.
- **Ensure adequate and ongoing consultation** with relevant stakeholders, including producers, surrounding communities, civil society groups, and academics, including for the development of the next agricultural policy framework (GBC, 2021)
- **Fully implement and adequately fund the proposed National Adaptation Strategy** in a way that supports producers and surrounding communities while leveraging opportunities for alternative and local food systems to build community resilience (Hammill et al., 2021).
- **Empower regional networks and local planning authorities** to develop local solutions, including building infrastructure projects to protect from weather events such as flooding and droughts. These could also support knowledge transfer within communities through farmer-to-farmer learning events.
- **Ensure domestic food and agricultural policies align with international commitments** on climate change and sustainability, including the Paris Agreement, the Aichi Biodiversity Targets, and the Sustainable Development Goals. This should include setting related domestic targets and transparently reporting on progress.

- **Consider developing a pan-Canadian soil health strategy** or other opportunities for shared approaches to soil health, in collaboration with diverse groups (see Equiterre & Greenbelt Foundation, 2021). This could help develop consensus and a long-term action plan to improve soil health to the benefit of producers and the environment.
- **Integrate and foreground equity, diversity, and inclusion policies and programs** to reduce barriers to entry in agriculture, support the leadership of those most impacted by existing inequities, advance reconciliation, and ensure the ongoing competitiveness of the sector (see Farmers for Climate Solutions Task Force, 2021).

As Canada moves into an uncertain climate future, rethinking agriculture on the Prairies may require some significant imagination, but this also provides us with an opportunity to go in entirely new directions. Working with multiple stakeholders and Canadian communities, as well as Prairie producers, will allow for a new, more sustainable vision of Prairie farming to emerge.

Further Reading

Many organizations recently have come out with recommendations on ways to support a more sustainable transition of how we produce and harvest food in Canada. The following are some of the reports that have made sustainable food production and/or green recovery from COVID-19 a priority:

In Canada:

Corkal, V., Gass, P., & Cosbey, A. (2020). *Green strings: Principles and conditions for a green recovery from COVID-19 in Canada*. https://www.iisd.org/library/green-strings-recovery-covid-19-canada

Équiterre & Greenbelt Foundation. (2021). *The power of soil: An agenda for change to benefit farmers and climate resilience*. https://www.equiterre.org/sites/fichiers/powerofsoil.pdf

Farmers for Climate Solutions. (2020). *A better future starts on the farm: Recommendations for recovery from COVID-19 in Canadian agriculture*. https://farmersforclimatesolutions.ca/s/FCS-Recommendations-for-recovery-from-COVID-19-in-Canadian-agriculture-EN-web.pdf

Farmers for Climate Solutions Task Force. (2021). *A down payment for a resilient and low-GHG farm future: A $300 million plan to reduce agricultural GHGs by 10 Megatonnes and lay the groundwork for widespread adoption of climate-friendly farming in APF 2023*. https://static1.squarespace.com/static/5dc5869672cac01e07a8d14d/t/603cf540ca355d0ac5009619/1614607684484/FCS_BudgetRecommendation2021.pdf

Green Budget Coalition. (2021). *Recommendations for Budget 2022*. https://greenbudget.ca/wp-content/uploads/sites/4/2021/10/Green-Budget-Coalitions-Recommendations-for-Budget-2022-October-1-2021.pdf

Elsewhere:

Henderson, B., Frezal, C., & Flynn, E. (2020). *A survey of GHG mitigation policies for the agriculture, forestry and other land use sector.* Organisation for Economic Co-operation and Development. https://doi.org/10.1787/18156797

Mitchell, C. (2020). *Revitalizing farm communities with a Green New Deal. Data for progress.* https://www.filesforprogress.org/memos/revitalizing-farm-communities-with-a-green-new-deal.pdf

References

Advisory Council on Economic Growth. (2017). *Unleashing the growth potential of key sectors.* Department of Finance. https://www.budget.gc.ca/aceg-ccce/pdf/key-sectors-secteurs-cles-eng.pdf

Agricultural Research and Extension Council of Alberta. (2020). *Alberta Environmental Farm Plan.* https://www.albertaefp.com

Agriculture and Agri-Food Canada. (2019). *Food policy for Canada: Everyone at the table.*

Agriculture and Agri-Food Canada. (2020a). *Canada: Outlook for principal field crops.* https://www.agr.gc.ca/eng/crops/reports-and-statistics-data-for-canadian-principal-field-crops/canada-outlook-for-principal-field-crops-2020-11-20/?id=1605906326201

Agriculture and Agri-Food Canada. (2020b). *Canadian Agricultural Partnership.* https://agriculture.canada.ca/en/about-our-department/key-departmental-initiatives/canadian-agricultural-partnership

Aktar, W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: Their benefits and hazards. *Interdisciplinary Toxicology, 2*(1), 1–12. https://doi.org/10.2478/v10102-009-0001-7

Alston, M. (2012). Rural male suicide in Australia. *Social Science & Medicine, 74*(4), 515–522. https://doi.org/10.1016/j.socscimed.2010.04.036

ALUS. (2021). *What we do.* ALUS Canada. https://alus.ca/what-we-do/

Amichev, B. Y., Bentham, M. J., Cerkowniak, D., Kort, J., Kulshreshtha, S., Laroque, C. P., & Van Rees, K. C. J. (2015). Mapping and quantification of planted tree and shrub shelterbelts in Saskatchewan, Canada. *Agroforestry Systems, 89*(1), 49–65.

Arbuthnott, B. K. & Schmutz, J. K. (2013, April). PFRA Community Pastures: History and Drama of a Prairie Commons. *SaskNotes.* Canadian Centre for Policy Alternatives. https://www.policyalternatives.ca/sites/default/files/uploads/publications/Saskatchewan%20Office/2013/04/SKnotes_PFRA_0.pdf

Argue, G., Stirling, B., & Diaz, P. (2003). Agricultural chemicals and agri-business. In H. P. Diaz, J. Jaffe & R. Sterling (Eds.), *Farm communities at the crossroads: Challenge and resistance* (pp. 207–222). Canadian Plains Research Centre, University of Regina.

Atkinson, R. & McCrorie, J. N. (2003). The decline of agrarian radicalism on the Canadian Prairies. In H. P. Diaz, J. Jaffe & R. Sterling (Eds.), *Farm communities at the crossroads: Challenge and resistance* (pp. 323–328). Canadian Plains Research Centre, University of Regina.

Audsley, E., Stacey, K., Parsons, D. J., & Williams, A. G. (2009). *Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use.* Cranfield University. https://dspace.lib.cranfield.ac.uk/bitstream/handle/1826/3913/Estimation_of_the_greenhouse_gas_emissions_from_agricultural_pesticide_manufacture_and_use-2009.pdf;jsessionid=DA64E2C75C0A22F05081DBA8DD35BDC6?sequence=1

Basche, A. D., Miguez, F. E., Kaspar, T. C., & Castellano, M. J. (2014). Do cover crops increase or decrease nitrous oxide emissions? A meta-analysis. *Journal of Soil and Water Conservation, 69*(6), 471–482. https://doi.org/10.2489/jswc.69.6.471

Bashi, Z., McCullough, R., Ong, L., & Ramirez, M. (2019). *Alternative proteins: The race for market share is on.* McKinsey & Company. https://www.mckinsey.com/industries/agriculture/our-insights/alternative-proteins-the-race-for-market-share-is-on

Bauta Family Initiative on Canadian Seed. (n.d.). *Field crops: Participatory plant breeding for field crops.* http://www.seedsecurity.ca/en/programs/create/field-crops#:~:text=Our%20Participatory%20Plant%20Breeding%20(PPB,regional%20climate%20and%20farm%20needs

Bayat, A. R., Tapio, I., Vilkki, J., Shingfield, K. J., & Leskinen, H. (2018). Plant oil supplements reduce methane emissions and improve milk fatty acid composition in dairy cows fed grass silage-based diets without affecting milk yield. *Journal of Dairy Science, 101*(2), 1136–1151. https://doi.org/10.3168/jds.2017-13545

Climate & Agriculture Initiative BC. (2021). *About us.* https://www.climateagriculturebc.ca/about-us/

B.C. Ministry of Agriculture. (2019). *Climate Change Adaptation Pathways Framework: Supporting sustainable local food in B.C.* https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/climate-action/cc-adaptation-pathways-framework.pdf

Beckman, J., Ivanic, M., Jelliffe, J., Baquedano, F., & Scott, S. (2020). *Economic and food security impacts of agricultural input reduction under the European Union Green Deal's Farm to Fork and Biodiversity Strategies.* (U.S. Department of Agriculture, Economic Research Service, EB-30). http://www.ers.usda.gov/publications/pub-details/?pubid=99740

Beingessner, P. (2003). Saskatchewan short line rails. In H. P. Diaz, J. Jaffe & R. Sterling (Eds.), *Farm communities at the crossroads: Challenge and resistance* (pp. 191–203). Canadian Plains Research Centre, University of Regina.

Binkley, A. (2020, September 16). *Federal carbon offset program leaves out key agriculture initiative.* National Newswatch. https://www.nationalnewswatch.com/2020/09/16/federal-carbon-offset-program-leaves-out-key-agriculture-initiative/

Bizikova, L., Waldick, R., & Larkin, P. (2017). *Can we measure resilience? Reducing agriculture's vulnerability to climate change.* International Institute for Sustainable Development. https://www.iisd.org/system/files/publications/reducing-agriculture-vulnerability-climate-change.pdf

Bolla, S. (2020). *European Union: Food labeling initiatives in the EU Farm to Fork Strategy* (No. E42020-0027). United States Department of Agriculture. https://www.fas.usda.gov/data/european-union-food-labeling-initiatives-eu-farm-fork-strategy

Bousquet, F., Botta, A., Alinovi, L., Barreteau, O., Bossio, D., Brown, K., Caron, P., Cury, P., d'Errico, M., DeClerck, F., Dessard, H., Enfors Kautsky, E., Fabricius, C., Folke, C., Fortmann, L., Hubert, B., Magda, D., Mathevet, R., Norgaard, R. B., Quinlan, A., & Staver, C. (2016). Resilience and development: Mobilizing for transformation. *Ecology and Society, 21*(3), 40.

Brandt, S. A., Thomas, A. G., Olfert, O. O., Leeson, J. Y., Ulrich, D. & Weiss, R. (2010). Design, rationale and methodological considerations for a long term alternative cropping experiment in the Canadian plain region. *European Journal of Agronomy, 32,* 73–79.

Brasser, T. (2019). *Plains Indigenous Peoples in Canada.* The Canadian Encyclopedia. https://www.thecanadianencyclopedia.ca/en/article/aboriginal-people-plains

Brookes, G., & Barfoot, P. (2017). Environmental impacts of genetically modified (GM) crop use 1996–2015: Impacts on pesticide use and carbon emissions. *GM Crops & Food, 8*(2), 117–147. https://doi.org/10.1080/21645698.2017.1309490

Bruneau, J., Corkal, D. R., Pietroniro, E., Toth, B., & van der Kamp, G. (2009.) Human activities and water use in the South Saskatchewan River Basin. In G. Marchildon (Ed.), *A dry oasis: Institutional adaptation to climate on the Canadian Plains* (pp. 129–152). CPRC Press.

Burton, R. J. F. (2004). Seeing through the 'Good Farmer's' eyes: Towards developing an understanding of the social symbolic value of 'productivist' behaviour. *Sociologia Ruralis, 44,* (2), 195–215. https://doi.org/10.1111/j.1467-9523.2004.00270.x.

Burton, R. J. F., Forney, J., Stock, P., & Sutherland, L. (2020). *The good farmer: Culture and identity in food and agriculture.* Routledge.

Bush, E., & Lemmen, D. (2019). *Canada's changing climate report.* Government of Canada. https://changingclimate.ca/site/assets/uploads/sites/2/2019/04/CCCR_FULLREPORT-EN-FINAL.pdf

California Air Resources Board. (2018, December). *Emissions inventory for agricultural diesel vehicles.* https://ww3.arb.ca.gov/msei/ordiesel/ag2011invreport.pdf

Canada Revenue Agency. (2019, February 21). *Fuel charge relief.* https://www.canada.ca/en/revenue-agency/services/tax/excise-taxes-duties-levies/fuel-charge/relief.html

Canadian Agri-Food Trade Alliance. (2017). *Agri-food exports.* http://cafta.org/agri-food-exports/

Canadian Institute for Climate Choices. (2020). Manitoba's Climate and Green Plan Implementation Act 2018. https://climatechoices.ca/publications/manitobas-climate-and-green-plan-implementation-act-2018/

Carter, S. (1992). *Lost harvest: Prairie reserve farmers and government policy.* McGill-Queen's University Press.

Carter, S. (2016). *Imperial plots: Women, land, and the spadework of British colonialism on the Canadian Prairies.* University of Manitoba Press.

CBC News. (2021, May 31). *Temporary foreign workers at Quebec greenhouse denounce cramped and unsanitary living conditions.* https://www.cbc.ca/news/canada/montreal/temporary-foreign-workers-demers-greenhouse-quebec-1.6047425

Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change, 4*(4), 287–291. https://doi.org/10.1038/nclimate2153

Chatterjee, A., & Clay, D. E. (2020). *Soil fertility management in agroecosystems.* John Wiley & Sons.

Clark, M. A., Domingo, N. G. G., Colgan, K., Thakrar, S. K., Tilman, D., Lynch, J., Azevedo, I. L., & Hill, J. D. (2020). Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science, 370*(6517), 705–708. https://doi.org/10.1126/science.aba7357

Clearwater, R. L., Martin, T., & Hoppe, T. (Eds.). (2016). *Environmental sustainability of Canadian agriculture* (Report #4 Agri-Environmental Indicators Report Series). Agriculture and Agri-Food Canada. https://publications.gc.ca/collections/collection_2016/aac-aafc/A22-201-2016-eng.pdf

Cohen, S., Bush, E., Zhang, X., Gillett, N., Bonsal, B., Derksen, C., Flato, G., Greenan, B., & Watson, E. (2019). Synthesis of findings for Canada's regions. In E. Bush & D.S. Lemmen (Eds.), *Canada's changing climate report* (pp. 424–443). Government of Canada. https://changingclimate.ca/CCCR2019/chapter/8-0/

Convention on Biological Diversity. (2020a, September 13). *Canada—National Targets.* https://www.cbd.int/countries/targets/?country=ca

Convention on Biological Diversity. (2020b, September 18). *Aichi Biodiversity Targets.* https://www.cbd.int/sp/targets/

Corkal, V., Levin, J., & Gass, P. (2020). *Canada's fossil fuel subsidies in 2020.* International Institute for Sustainable Development. https://www.iisd.org/sites/default/files/publications/canada-fossil-fuel-subsidies-2020-en.pdf

Corkal, V., Gass, P., & Cosbey, A. (2020). *Green strings: Principles and conditions for a green recovery from COVID-19 in Canada.* https://www.iisd.org/library/green-strings-recovery-covid-19-canada

Cunfer, G. (2005). *On the Great Plains: Agriculture and environment.* A&M University Press.

Dale, B. (2020). Alliances for agroecology: From climate change to food system change. *Agroecology and Sustainable Food Systems, 44*(5), 629–652. https://doi.org/10.1080/21683565.2019.1697787

Daschuk, J. (2013). *Clearing the plains: Disease, politics of starvation, and the loss of Aboriginal life.* University of Regina Press.

Davidson-Hunt, I. (2003). Indigenous lands management, cultural landscapes, and Anishinaabe people of Shoal Lake, Northwestern Ontario, Canada. *Environments, 31*(1), 21–41.

Department of Finance. (2021). *Budget 2021: A recovery plan for jobs, growth, and resilience.* https://www.budget.gc.ca/2021/home-accueil-en.html

Deryng, D., Sacks, W. J., Barford, C. C., & Ramankutty, N. (2011). Simulating the effects of climate and agricultural management practices on global crop yield. *Global Biogeochemical Cycles, 25*(2). https://doi.org/10.1029/2009GB003765

Desmarais, A. A., Qualman, D., Magnan, A. & Wiebe, N. (2017). Investor ownership or social investment? Changing farmland ownership in Saskatchewan, Canada. *Agriculture and Human Values, 34* (1), 149–166. https://doi.org/10.1007/s10460-016-9704-5

Deutsch, C. A., Tewksbury, J. J., Tigchelaar, M., Battisti, D. S., Merrill, S. C., Huey, R. B., & Naylor, R. L. (2018). Increase in crop losses to insect pests in a warming climate. *Science, 361*(6405), 916–919. https://doi.org/10.1126/science.aat3466

Drever, C. R., Cook-Patton, S. C., Akhter, F., Badiou, P. H., Chmura, G. L., Davidson, S. J., Desjardins, R. L., Dyk, A., Fargione, J. E., Fellows, M., Filewod, B., Hessing-Lewis, M., Jayasundara, S., Keeton, W. S., Kroeger, T., Lark, T. J., Le, E., Leavitt, S. M., LeClerc, M.-E., … Kurz, W. A. (2021). Natural climate solutions for Canada. *Science Advances, 7*(23), eabd6034. https://doi.org/10.1126/sciadv.abd6034

Dusyk, N., Turcotte, I., Gunton, T., McBain, S., Penney, N., Pickrell-Barr, J., & Pope, M. (2021). *All hands on deck: An assessment of provincial, territorial and federal readiness to deliver a safe climate.* Pembina Institute.

Dyer, J. A., & Desjardins, R. L. (2006). Carbon dioxide emissions associated with the manufacturing of tractors and farm machinery in Canada. *Biosystems Engineering, 93*(1), 107–118. https://doi.org/10.1016/j.biosystemseng.2005.09.011

Eaton, E. (2013). *Growing resistance: Canadian farmers and the politics of genetically modified wheat.* University of Manitoba Press.

Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). (2006). *2006 IPCC guidelines for national greenhouse gas inventories.* http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Environment and Climate Change Canada. (2016). *Pan-Canadian framework on clean growth and climate change: Canada's plan to address climate change and grow the economy.* http://publications.gc.ca/collections/collection_2017/eccc/En4-294-2016-eng.pdf

Environment and Climate Change Canada. (2019a). *Achieving a sustainable future: A federal sustainable development strategy for Canada 2019 to 2022.* http://fsds-sfdd.ca/downloads/FSDS_2019-2022.pdf

Environment and Climate Change Canada. (2019b). *Canada's fourth biennial report on climate change.* https://unfccc.int/sites/default/files/resource/br4_final_en.pdf

Environment and Climate Change Canada. (2020a). *Canada's official greenhouse gas inventory—Economic sector dataset.* http://donnees.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/GHG_Econ_Can_Prov_Terr.csv

Environment and Climate Change Canada. (2020b). *National inventory report 1990-2018: Greenhouse gas sources and sinks in Canada.* https://unfccc.int/documents/224829

Environment and Climate Change Canada. (2020c). *A healthy environment and a healthy economy.* https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

Environment and Climate Change Canada. (2021). *Canada's enhanced nationally determined contribution.* https://www.canada.ca/en/environment-climate-change/news/2021/04/canadas-enhanced-nationally-determined-contribution.html

Epp, R. (2008). *We are all Treaty People: Prairie essays.* University of Alberta Press.

Equiterre & Greenbelt Foundation. (2021). *The power of soil: An agenda for change to benefit farmers and climate resilience.* https://www.equiterre.org/sites/fichiers/powerofsoil.pdf

European Commission. (2020 September 17). *State of the Union: Questions & answers on the 2030 climate target plan.* https://ec.europa.eu/commission/presscorner/detail/en/QANDA_20_1598

Farmers for Climate Solutions. (2020). *A better future starts on the farm: Recommendations for recovery from COVID-19 in Canadian agriculture.* https://farmersforclimatesolutions.ca/s/FCS-Recommendations-for-recovery-from-COVID-19-in-Canadian-agriculture-EN-web.pdf

Farmers for Climate Solutions. (2021). *Climate action in agriculture around the world.* https://static1.squarespace.com/static/5dc5869672cac01e07a8d14d/t/602eab0d76c2852b0c4de76b/1613671182008/FCS-Climate_action_in_agriculture_around_the_world.pdf

Farmers for Climate Solutions Task Force. (2021). *A down payment for a resilient and low-GHG farm future: A $300 million plan to reduce agricultural GHGs by 10 Megatonnes and lay the groundwork for widespread adoption of climate-friendly farming in APF 2023.* https://static1.squarespace.com/static/5dc5869672cac01e07a8d14d/t/603cf540ca355d0ac5009619/1614607684484/FCS_BudgetRecommendation2021.pdf

Fawcett-Atkinson, M. (2020a, October 5). A 1930s-era federal agency helped farms recover from an ecological crisis. It's time for a replacement, advocates say. *National Observer.* https://www.nationalobserver.com/2020/10/05/news/1930s-era-federal-agency-helped-farms-recover-ecological-crisis-its-time-replacement

Fawcett-Atkinson, M. (2020b, October 28). Urban gardens growing strong amid COVID pandemic. *National Observer.* https://www.nationalobserver.com/2020/10/28/news/urban-gardens-growing-strong-covid-pandemic

Fletcher, A. J., & Knuttila, E. (2016). Gendering change: Canadian farm women respond to drought. In H. Diaz, M. Hurlbert, & J. Warren (Eds.), *Vulnerability and adaptation to drought: The Canadian Prairies and South America* (pp. 159–177). University of Calgary Press. www.jstor.org/stable/j.ctv6gqwv1

Fletcher, A. J., Sah Akwen, N., Hurlbert, M., & Diaz, H. P. (2020). "You relied on God and your neighbour to get through it": Social capital and climate change adaptation in the rural Canadian Prairies. *Regional Environmental Change, 20*(61), 1–15.

Food and Agriculture Organization of the United Nations. (n.d.). *Pesticides indicators.* http://www.fao.org/faostat/en/#data/EP

Food and Agriculture Organization of the United Nations. (2021). *Desert locust crisis: FAO in emergencies*. http://www.fao.org/emergencies/crisis/desertlocust/en/

Food Secure Canada & FLEdGE. (2017). *Summary table: FPT policy landscape for sustainable agriculture*. https://foodsecurecanada.org/sites/foodsecurecanada.org/files/summary_table_fpt_policy_landscape_for_sustainable_agriculture_2017.pdf

Gan, Y., Liang, C., Wang, X., & McConkey, B. (2011). Lowering carbon footprint of durum wheat by diversifying cropping systems. *Field Crops Research, 122*(3), 199–206. https://doi.org/10.1016/j.fcr.2011.03.020

General Mills. (n.d.). *Regenerative agriculture.* http://www.generalmills.com/en/Responsibility/Sustainability/Regenerative-agriculture

Gliessman, S. R. (2007). *Agroecology: The ecology of sustainable food systems.* CRC Press.

Goldman, S., Aspenson, A., Bhatnager, P., & Martin, R. (2021). *Essential and in crisis: A review of the public health threats facing farmworkers in the US.* John Hopkins Center for a Livable Future.

Government of Alberta. (2004, June). Greenhouse gasses: Things you need to know. *Manure management and greenhouse gases, 11.* https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/ba3468a2a8681f69872569d60073fde1/463f9f3b4a0c26f787257035005b6a33/$FILE/GHGBulletinNo11Manuremanagement.pdf

Government of Alberta. (2008). *Alberta's 2008 Climate Change Strategy: Responsibility, leadership, action.* https://open.alberta.ca/dataset/e86a9861-aa19-400e-bb7a-909ef8ccfe46/resource/ad5754f4-cc7f-40bf-a2ad-0775bd83ba7e/download/4063885-2008-albertas-2008-climate-change-strategy.pdf

Government of Alberta. (2020a). *Agriculture and forestry business plan 2020-2023.* https://open.alberta.ca/dataset/87074796-5715-4a79-b3f6-e12e9a699c70/resource/b2999d36-2d06-46b6-8d1d-3a649c252675/download/agriculture-and-forestry-business-plan-2020-23.pdf

Government of Alberta. (2020b). *Alberta Emission Offset System.* https://www.alberta.ca/alberta-emission-offset-system.aspx

Government of Alberta. (2020c). *Environmental stewardship and climate change—Producer.* https://cap.alberta.ca/CAP/program/STEW_PROD

Government of Alberta. (2020d). Results Driven Agriculture Research. https://rdar.ca/

Government of British Columbia. (n.d.). *Increasing agricultural adaptation.* https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/agricultural-land-and-environment/climate-action/adapting-to-climate-change/increasing-agricultural-adaptation

Government of Canada. (2018). *Canada's implementation of the 2030 Agenda for Sustainable Development: Voluntary national review.* https://www.deslibris.ca/ID/10097786

Government of Canada. (2020a). *Canada's state of trade: The early impacts of COVID-19 on trade.* Office of the Chief Economist/Global Affairs Canada. https://www.international.gc.ca/gac-amc/assets/pdfs/publications/State-of-Trade-2020_eng.pdf

Government of Canada. (2020b). *Disaster Mitigation and Adaptation Fund: Program details.* https://www.infrastructure.gc.ca/dmaf-faac/details-eng.html

Government of Canada. (2021). *Canadian Centre for Climate Services.* https://www.canada.ca/en/environment-climate-change/services/climate-change/canadian-centre-climate-services.html

Government of Ireland. (2020). *Ag Climatise – A roadmap towards climate neutrality.* https://www.gov.ie/en/publication/07fbe-ag-climatise-a-roadmap-towards-climate-neutrality/

Government of Manitoba. (n.d.). *Environmental Farm Plan.* Province of Manitoba – Agriculture. https://www.gov.mb.ca/agriculture/environment/environmental-farm-plan/

Government of Manitoba. (2019a). *The Manitoba Protein Advantage: A strategy for sustainable protein production, processing and innovation.* https://www.gov.mb.ca/agriculture/protein/pubs/manitoba-protein-strategy.pdf

Government of Manitoba. (2019b, June 11). *Province announces $52-million "GROW" Fund to support wetland protection and watershed management* [Press release]. Province of Manitoba. https://news.gov.mb.ca/news/index.html?item=45394

Government of Manitoba. (2020a). *Assurance: Watershed ecological goods and services.* Province of Manitoba – Agriculture. https://www.gov.mb.ca/agriculture/environment/ecological-goods-and-services/watershed-egs.html

Government of Manitoba. (2020b). *Assurance: Environment beneficial management practices (BMPs)*. Province of Manitoba – Agriculture. https://www.manitoba.ca/agriculture/environment/environmental-farm-plan/assurance-bmp.html

Government of Manitoba. (2020c). *Ecological goods and services and natural capital.* Province of Manitoba – Agriculture. https://www.gov.mb.ca/agriculture/environment/ecological-goods-and-services/index.html

Government of New Zealand. (2020). *Hill Country Erosion Programme for councils.* https://www.mpi.govt.nz/forestry/funding-tree-planting-research/hill-country-erosion-programme

Government of Ontario. (2017). *Reducing energy use in grain dryers: Factsheet.* http://www.omafra.gov.on.ca/english/engineer/facts/17-001.htm#2

Government of Saskatchewan. (n.d.). *Environmental sustainability and climate change*. https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/canadian-agricultural-partnership-cap/environmental-sustainability-and-climate-change

Government of Saskatchewan. (2020). *Saskatchewan's growth plan.* https://www.saskatchewan.ca/government/budget-planning-and-reporting/plan-for-growth

Green Budget Coalition. (2021). *Recommendations for Budget 2022.* https://greenbudget.ca/wp-content/uploads/sites/4/2021/10/Green-Budget-Coalitions-Recommendations-for-Budget-2022-October-1-2021.pdf

Hammill, A., Parry, J., Ledwell, C., & Dazé, A. (2021). *Toward a national adaptation strategy for Canada: Key insights from global peers.* International Institute for Sustainable Development. https://www.iisd.org/publications/national-adaptation-strategy-canada

Hannah, L., Roehrdanz, P. R., Krishna Bahadur K. C., Fraser, E. D. G., Donatti, C. I., Saenz, L., Wright, T. M., Hijmans, R. J., Mulligan, M., Berg, A., & van Soesbergen, A. (2020). The environmental consequences of climate- driven agricultural frontiers. *PLoS ONE, 15*(2), 1–19. https://doi.org/10.1371/journal.pone.0228305.

He, W., Yang, J., Qian, B., Drury, C., Hoogenboom, G., He, P., Lapen, D., & Zhou, W. (2018). Climatic change impacts on crop yield, soil water balance and nitrate leaching in the semiarid and humid regions of Canada. *PLoS ONE 13*(11), e0207370. https://doi.org/10.1371/journal.pone.0207370

Heimpel, G. E., Yang, Y., Hill, J. D., & Ragsdale, D. W. (2013). Environmental consequences of invasive species: Greenhouse gas emissions of insecticide use and the role of biological control in reducing emissions. *PLoS ONE, 8*(8). https://doi.org/10.1371/journal.pone.0072293

Henderson, B., Frezal, C., & Flynn, E. (2020). *A survey of GHG mitigation policies for the agriculture, forestry and other land use sector.* Organisation for Economic Co-operation and Development. https://doi.org/10.1787/18156797

Herriot, T. (2016). *Towards a Prairie atonement.* University of Regina Press

Hurlbert, M. (2018). The challenge of integrated flood risk governance: Case studies in Alberta and Saskatchewan, Canada. *International Journal of River Basin Management, 16*(3), 287–297. https://doi.org/10.1080/15715124.2018.1439495

Hurlbert, M., & Pittman, J. (2014). Exploring adaptive management in environmental farm programs in Saskatchewan, Canada. *Journal of Natural Resources Policy Research, 6*(2–3), 195–212. https://doi.org/10.1080/19390459.2014.915131

Institut national de la recherche agronomique. (2019, June 13). *Storing 4 per 1000 carbon in soils: the potential in France.* https://www.inrae.fr/en/news/storing-4-1000-carbon-soils-potential-france

Institute for Agriculture and Trade Policy & National Family Farm Coalition. (2020). *Why carbon markets won't work for agriculture.* https://www.iatp.org/sites/default/files/2020-02/2020_01_CarbonMarketsAndAg_FINAL.pdf

Intergovernmental Panel on Climate Change. (2019). Summary for Policymakers. In *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

IPES-Food. (2016). *From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems.* International Panel of Experts on Sustainable Food Systems. http://www.ipes-food.org/_img/upload/files/UniformityToDiversity_FULL.pdf

Isaac, M. E., Ryan S., Isakson, B. D., Levkoe, C. Z., Hargreaves, S. K., Méndez, V. E., Wittman, H., Hammelman, C., Langill, J. C., Martin, A. R., Nelson, E., Ekers, M., Borden, K. A., Gagliardi, S., Buchanan, S., Archibald, S., & Gálvez Ciani, A. (2018). Agroecology in Canada: Towards an integration of agroecological practice, movement and science. *Sustainability: Special Issue on Agroecology for the Transition Towards Social-Ecological Sustainability, 10*(3299), 1–23. https://doi.org/10.3390/su10093299.

Isai, V. (2021, August 9). Canadian wildfires could intensify from a looming heat wave. *New York Times*. https://www.nytimes.com/2021/08/09/world/canada/canada-wildfires.html

Jayas, D. S., & White, N. D. G. (2003). Storage and drying of grain in Canada: Low cost approaches. *Food Control, 14*(4), 255–261. https://doi.org/10.1016/S0956-7135(03)00014-8

Jing, Q., Bélanger, G., Qian, B., and Baron, V. (2013). Timothy yield and nutritive value under climate change in Canada. *Agronomy Journal, 105*(6). https://doi.org/10.2134/agronj2013.0195

Jing, Q., Huffman, T., Shang, J., Liu, J., Pattey, E., Morrison, M., Jego, G., & Qian, B. (2017). Modelling soybean yield responses to seeding date under projected climate change scenarios. *Canadian Journal of Plant Science,* 97, 1152–1164. https://doi.org/10.1139/cjps-2017-0065v

Johnstone, S., & Mazo, J. (2011). Global warming and the Arab Spring. *Survival, 53*(2), 11–17. https://doi.org/10.1080/00396338.2011.571006

Kneen, B. (1990). *Trading up: How Cargill, the world's largest grain company, is changing Canadian agriculture.* New Canada Publications.

Kulshreshtha, S. (2019, June 28). Resiliency of Prairie agriculture to climate change. *Intechopin*. https://doi.org/10.5772/intechopen.87098

Kurz, W., Dymond, C., Stinson, G., Rampley, G. J., Neilson, E. T., Carroll, A. L., Ebata, T., & Safranyik, L. (2008). Mountain pine beetle and forest carbon feedback to climate change. *Nature, 452,* 987–990. https://doi.org/10.1038/nature06777

Kuyek, D. (2007). *Good crop/bad crop: Seed politics and the future of food in Canada.* Between the Lines.

Laforge, J. M. L., & Levkoe, C. Z. (2018). Seeding agroecology through new farmer training in Canada: Knowledge, practice, and relational identities. *Local Environment: The International Journal of Justice and Sustainability, 23*(10), 991–1007. https://doi.org/10.1080/13549839.2018.1515901.

Laforge, J. M. L., & McLachlan, S. M. (2018). Learning Communities and new farmer knowledge in Canada. *Geoforum, 96,* 256–67. https://doi.org/10.1016/j.geoforum.2018.07.022

Lamb-Yorski, M. (2017, May 9). Rancher gifts land to Esk'etemc during title and rights ceremony. *The Williams Lake Tribune*. https://www.wltribune.com/news/rancher-gifts-land-to-esketemc-during-title-and-rights-ceremony/

LeBel, J. (2021, April 13). *Cargill in London, Ont., halts production as COVID-19 case count climbs to 82.* Global News. https://globalnews.ca/news/7754875/cargill-london-ont-covid-19-outbreak/

Leckie, G. (1993). Female farmers in Canada and the gender relations of a restructuring agricultural system. *Canadian Geographer 37*(3), 212–30. https://doi.org/10.1111/j.1541-0064.1993.tb00298.x

Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature, 529*(7584), 84–87. https://doi.org/10.1038/nature16467

Li, G., Zhang, X., Cannon, A. J., Murdock, T., Sobie, S., Zwiers, F., Anderson, K., & Qian, B. (208). Indices of Canada's future climate for general and agricultural adaptation applications. *Climatic Change, 148,* 249–63. https://link.springer.com/article/10.1007/s10584-018-2199-x

Lillo, A., Matteau, J.-P., Kokulan, V., & Benalcazar, P. (2019). The contribution of wetlands towards a sustainable agriculture in Canada. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.3484143

Lind, C. (2003). Growing community as a response to globalization. In H. P. Diaz, J. Jaffe, and R. Sterling (Eds.), *Farm communities at the crossroads: Challenge and resistance* (pp 77–90). Canadian Plains Research Centre, University of Regina.

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science, 333*(6042), 616–620. https://doi.org/10.1126/science.1204531

Magdoff, F., & van Es, H. (2010). *Building soils for better crops: Sustainable soil management.* Sustainable Agriculture Research and Education.

Magnan, A. (2011). The limits of farmer-control: Food sovereignty and conflicts over the Canadian Wheat Board. In H. Wittman, A. A. Desmarais, and N. Wiebe (Eds.), *Food sovereignty in Canada: Creating just and sustainable food systems* (pp 114–133).: Fernwood.

Mandryk, M. (2019, April 12). Prairie Resilience plan does not offer enough focus on reducing GHG emissions. *Regina Leader Post.* https://leaderpost.com/opinion/columnists/prairie-resilience-plan-does-not-offer-enough-focus-on-reducing-ghg-emissions

Manitoba Habitat Heritage Corporation. (2021). *The Conservation and GROW Trusts.* https://mhhc.mb.ca/the-conservation-trust/

Manitoba Sustainable Development. (2017). *A made-in-Manitoba climate and green plan: Hearing from Manitobans.* Government of Manitoba. http://digitalcollection.gov.mb.ca/awweb/pdfopener?smd=1&did=25794&md=1

Marchildon, G. P. (2009). The Prairie Farm Rehabilitation Administration: Climate crisis and federal-provincial relations during the Great Depression. *Canadian Historical Review 90*(2), 275–301.

Marchildon, G. P., Kulshreshtha, S., Wheaton, E., & Sauchyn, D. (2008). Drought and institutional adaptation in the Great Plains of Alberta and Saskatchewan, 1914-1939. *Natural Hazards, 45*(3): 391–411. https://doi.org/10.1007/s11069-007-9175-5.

MarketsandMarkets. (2021). *Plant-based protein market by source, and region—Global forecast to 2026.* https://www.reportlinker.com/p05949871/Plant-based-Protein-Market-by-Source-Type-Form-Application-And-Region-Global-Forecast-to.html?utm_source=PRN

Massie, M. (2014). *Forest Prairie Edge: Place history in Saskatchewan.* University of Manitoba Press.

Meticulous Research. (2020). *Meat substitute market by product type (tofu, TVP, burger patties, sausages, meatballs, nuggets), source (soy protein, wheat protein), and distribution channel (business to business and business to customers)—Global forecast To 2027* (MRFB-104267). https://www.meticulousresearch.com/product/meat-substitute-market-4969

Migrant Rights Network. (2020, May 8). *Migrants are the food chain –We sustain the world.* https://migrantrights.ca/migrantfoodchain/

Milburn, L.-A. S., Mulley, S. J., & Kline, C. (2010). The end of the beginning and the beginning of the end: The decline of public agricultural extension in Ontario. *Journal of Extension, 48*(6). https://www.joe.org/joe/2010december/a7.php

Milton, T. (2020, September 11). *KAP responds to federal GHG offset system.* Farms.Com. https://www.farms.com/ag-industry-news/kap-responds-to-federal-ghg-offset-system-979.aspx

Monllor, N. (2012). *Farm entry: A comparative analysis of young farmers, their pathways, attitudes and practices in Ontario (Canada) and Catalunya (Spain)*. https://www.accesstoland.eu/IMG/pdf/monllor_farm_entry_report_2012.pdf

Montes, F., Meinen, R., Dell, C., Rotz, A., Hristov, A. N., Oh, J., Waghorn, G., Gerber, P. J., Henderson, B., Makkar, H. P. S., & Dijkstra, J. (2013). SPECIAL TOPICS – Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. *Journal of Animal Science, 91*(11), 5070–5094. https://doi.org/10.2527/jas.2013-6584

National Farmers Union. (2020). *Creating the foundation for a climate-friendly post-pandemic food system for Canadians.* https://www.nfu.ca/wp-content/uploads/2020/08/2020-08-07-NFU-Pre-Budget-2021-Consultation-Brief.pdf

Natural Resources Canada. (2009). *Water use by the natural resources sector: Facts.* https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/www/pdf/com/resoress/publications/wateau/wateau-eng.pdf

Natural Resources Canada. (2018, August 22). *Building Regional Adaptation Capacity and Expertise (BRACE) Program.* https://www.nrcan.gc.ca/climate-change/impacts-adaptations/what-adaptation/building-regional-adaptation-capacity-and-expertise-brace-program/21324

Nickel, R. (2021, August 30). *Drought shrinks Canada's wheat crop to 14-year low, shrivels canola harvest.* CTVNews. https://www.ctvnews.ca/canada/drought-shrinks-canada-s-wheat-crop-to-14-year-low-shrivels-canola-harvest-1.5566422

Norrie, K., & Regehr T. D. (2014). *Crow's Nest Pass Agreement.* The Canadian Encyclopedia. https://www.thecanadianencyclopedia.ca/en/article/crows-nest-pass-agreement

Office of the Auditor General. (2008). Managing environmental programming – Agriculture and Agri-Food Canada. In *Report of the Commissioner of the Environment and Sustainable Development.* Government of Canada. https://www.oag-bvg.gc.ca/internet/English/parl_cesd_200812_03_e_31820.html#hd4a

Office of the Auditor General. (2017). *Report 2—Adapting to the impacts of climate change* (2017 Fall Reports of the Commissioner of the Environment and Sustainable Development). Government of Canada. https://www.oag-bvg.gc.ca/internet/English/parl_cesd_201710_02_e_42490.html

Office of the Auditor General. (2018). *Report 3—Conserving biodiversity* (2018 Spring Reports of the Commissioner of the Environment and Sustainable Development). Government of Canada. https://www.oag-bvg.gc.ca/internet/English/parl_cesd_201804_03_e_42994.html

Office of the Auditor General. (2019). *Report 1—Review of the 2018 progress report on the Federal Sustainable Development Strategy* (2018 Spring Reports of the Commissioner of the Environment and Sustainable Development). Government of Canada. https://www.oag-bvg.gc.ca/internet/English/parl_cesd_201912_01_e_43478.html

Olson, W. (2019). *Bison.* The Canadian Encyclopedia. https://www.thecanadianencyclopedia.ca/en/article/bison

Ontario Centre for Climate Impacts and Adaptation Resources. (2017). *Grappling with climate change impacts by strengthening agricultural extension in Ontario* [Policy brief]. http://www.climateontario.ca/doc/p_OCAAF/OCAAF-PolicyBriefOnAgriculturalExtension_FINAL.pdf

Oosterhuis, K. (2020, October 21). *Alberta government "getting out of" agriculture research with latest staff cuts: Former researcher.* RealAgriculture. https://www.realagriculture.com/2020/10/alberta-government-getting-out-of-agriculture-research-with-latest-staff-cuts-former-researcher/

Organic Council. (2017). *Investing in organic agriculture: A path to clean, inclusive, economic growth.* https://www.organiccouncil.ca/wordpress/wp-content/uploads/2017/05/Recommendations-for-NAPF-Nov30-final-1.pdf

Organisation for Economic Co-operation and Development. (2020). *Inventory of support measures for fossil fuels database.* https://www.oecd.org/fossil-fuels/data/

Organisation for Economic Co-operation and Development & Food and Agriculture Organization of the United Nations. (2020). *OECD-FAO agricultural outlook 2020-2029.* https://doi.org/10.1787/1112c23b-en

Owram, D. (1980). *Promise of Eden: The Canadian expansionist movement and the idea of the West, 1856–1900.* University of Toronto Press.

Parliament of Canada. (2021). Bill C-206: An Act to amend the Greenhouse Gas Pollution Pricing Act (qualifying farming fuel). https://www.parl.ca/LegisInfo/BillDetails.aspx?Language=E&billId=10866034&View=0

Paustian, K., Larson, E., Kent, J., Marx, E., & Swan, A. (2019). Soil C sequestration as a biological negative emission strategy. *Frontiers in Climate, 1.* https://doi.org/10.3389/fclim.2019.00008

Pearson, R., Stanton, J., Shoemaker, K., Aiello-Lammens, M., & Ersts, P. (2014). Life history and spatial traits predict extinction risk due to climate change. *Nature Climate Change, 4,* 217–221.

Philip, S. Y., Kew, S. F., van Oldenborgh, G. J., Yang, W., Vecchi, G. A., Anslow, F. S., Li, S., Seneviratne, S. I., Luu, L. N., Arrighi, J., Singh, R., van Aalst, M., Hauser, M., Schumacher, D. L., Marghidan, C. P., Ebi, K. L., Bonnet, R., Vautard, R., Tradowsky, J., … Otto, F. E. L. (n.d.). *Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada June 2021*. https://www.worldweatherattribution.org/wp-content/uploads/NW-US-extreme-heat-2021-scientific-report-WWA.pdf

Polachic, D. (2017, February 11). Reserve 107 documentary shows peaceful path to reconciliation. *Saskatoon StarPhoenix*. http://thestarphoenix.com/life/relationships/reserve-107-documentary-shows-peaceful-path-to-reconciliation

Pomeroy, J., Stewart, R., and Whitfield, P. (2015). The 2013 flood event in the South Saskatchewan and Elk River basins: Causes, assessment and damages. *Canadian Water Resources Journal, 41*(1–2). http://dx.doi.org/10.1080/07011784.2015.1089190

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., Lobell, D. B., & Travasso, M. I. (2014). Food security and food production systems. In C. B. Field et al. (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Working Group II Contribution of to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 485–533). Cambridge University Press. http://eprints.whiterose.ac.uk/110945/

Potyondi, B. (1995). *In Palliser's Triangle: Living in the grasslands, 1850–1930.* Purich.

Pratt, S. (2020, October 15). Green lentil demand expected to remain strong. *The Western Producer.* https://www.producer.com/markets/green-lentil-demand-expected-to-remain-strong/

Qian, B., De Jong, R., Huffman, T., Wang, H., and Yang, J. (2015). Projecting yield changes of spring wheat under future climate scenarios on the Canadian Prairies. *Theoretical and Applied Climatology, 123,* 651–669. https://doi.org/10.1007/s00704-015-1378-1

Qian, B., Jing, Q., Belanger, G., Shang, J., Huffman, T., Liu, J., & Hoogenboom, G. (2018). Simulated canola yield responses to climate change and adaptation in Canada. *Agronomy Journal,* 110 (1), 133–146. https://doi.org/10.2134/agronj2017.02.0076

Qian, B., Wang, H., He, Y., Liu, J., & De Jong, R. (2016). Projecting spring wheat yield changes on the Canadian Prairies: Effects of resolutions of a regional climate model and statistical processing. *International Journal of Climatology, 36*(10), 3492–3506. http://dx.doi.org/10.1002/joc.4571

Qualman, D. (2019). *Tackling the farm crisis and the climate crisis: A transformative strategy for Canadian farms and food systems.* National Farmers Union. https://www.nfu.ca/wp-content/uploads/2019/12/Tackling-the-Farm-Crisis-and-the-Climate-Crisis-Final-with-covers.pdf

RealAgriculture. (2017, December 4). *Saskatchewan farm groups applaud province's climate change strategy.* https://www.realagriculture.com/2017/12/saskatchewan-farm-groups-applaud-provinces-climate-change-strategy/

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management, 16,* 145–163. https://doi.org/10.1016/j.crm.2017.02.001

Rosen, K. (2021, August 31). *Help coming for Manitoba livestock producers impacted by drought.* CTVNews. https://winnipeg.ctvnews.ca/help-coming-for-manitoba-livestock-producers-impacted-by-drought-1.5568056

Rosset, P. M., & Altieri, M. A. (2017). *Agroecology: Science and politics.* Fernwood Publishing.

Roque, B.M., Venegas, M., Kinley, R.D., de Nys, R., Duarte, T.L., Yang, X., & Kebreab, E. (2021). Red seaweed (Asparagopsis taxiformis) supplementation reduces enteric methane by over 80 percent in beef steers. *PLoS ONE 16*(3), e0247820. doi.org/10.1371/journal.pone.0247820

Rosenzweig, C., Jones, J. W., Hatfield, J. L., Ruane, A. C., Boote, K. J., Thorburn, P., Antle, J. M., Nelson, G. C., Porter, C., Janssen, S., Asseng, S., Basso, B., Ewert, F., Wallach, D., Baigorria, G., & Winter, J. M. (2013). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. *Agricultural and Forest Meteorology, 170,* 166–182. https://doi.org/10.1016/j.agrformet.2012.09.011

Rural Routes to Climate Solutions. (2020). *About us.* https://rr2cs.ca/about/

Russell, P. A. (2012). *How agriculture made Canada: Farming in the 19th century.* McGill-Queen's University Press

Sachs, C., Barbercheck, M. E., Brasier, K., Kiernan, N. E., & Terman, A. R. (2016). *The rise of women farmers and sustainable agriculture*. University of Iowa Press.

Saha, D., Kaye, J. P., Bhowmik, A., Bruns, M. A., Wallace, J. M., & Kemanian, A. R. (n.d.). Organic fertility inputs synergistically increase denitrification-derived nitrous oxide emissions in agroecosystems. *Ecological Applications, 31*(7), e02403. https://doi.org/10.1002/eap.2403

Saskatchewan Environmental Society. (2019). *"Prairie resilience" is not enough.* http://environmentalsociety.ca/wp-content/uploads/2018/12/Prairie-Resilience-Is-Not-Enough-Full-Report-Final.pdf#page=33&zoom=100,0,0

Saskatchewan Soil Conservation Association (SSCA). (n.d.-a). *History.* https://ssca.ca/about/history

Saskatchewan Soil Conservation Association. (n.d.-b). *Membership.* https://ssca.ca/about/membership

Sauchyn, D., Davidson, D., & Johnston, M. (2020). Prairie provinces. In F. J. Warren, N. Lulham, & D. S. Lemmon (Eds.), *Canada in a changing climate: Regional perspectives report.* Government of Canada. https://www.nrcan.gc.ca/sites/nrcan/files/earthsciences/Prairie%20Provinces%20Chapter%20%E2%80%93%20Regional%20Perspectives%20Report.pdf

Savage, C. (2004). *Prairie: A natural history.* Greystone Books & David Suzuki Foundation.

Savary, S., Willocquet, L., Pethybridge, S. J., Esker, P., McRoberts, N., & Nelson, A. (2019). The global burden of pathogens and pests on major food crops. *Nature Ecology & Evolution, 3*(3), 430–439. https://doi.org/10.1038/s41559-018-0793-y

Schebesta, H., & Candel, J. J. L. (2020). Game-changing potential of the EU's Farm to Fork Strategy. *Nature Food, 1*(10), 586–588. https://doi.org/10.1038/s43016-020-00166-9

Schneider, R. & Bayne, E.M. (2015). Reserve design under climate change: From land facets back to ecosystem representation. *PLoS ONE, 10*(5). https://doi.org/10.1371/journal.pone.0126918

Schneider, R. R., Devito, K., Kettridge, N., & Bayne, E. (2016). Moving beyond bioclimatic envelope models: Integrating upland forest and peatland processes to predict ecosystem transitions under climate change in the Western Canadian Boreal Plain. *Ecohydrology, 9*(6), 899–908. https://doi.org/10.1002/eco.1707

Science Based Targets. (2021). *Companies taking action.* https://sciencebasedtargets.org/companies-taking-action?country=Canada&ambitionToggle=1

Senate Committee on Agriculture and Forestry. (2018). *Feast or famine: Impacts of climate change and carbon pricing on agriculture, agri-food and forestry.* Senate of Canada. https://sencanada.ca/content/sen/committee/421/AGFO/reports/Climate-Change_E_web.pdf

Skogstad, G. (1987). *The politics of agricultural policy-making in Canada* (1st ed.). University of Toronto Press.

Smith, W.N., Grant, B.B., Desjardins, R.L., Kroebel, R., Li, C., Qian, B., Worth, D.E., McConkey, B.G., & Drury, C.F. (2013). Assessing the effects of climate change on crop production and GHG emissions in Canada. *Agriculture, Ecosystems & Environment, 179,* 139–150. https://doi.org/10.1016/j.agee.2013.08.015

Sommerville, M. & Magnan, A. (2015). 'Pinstripes on the prairies': Examining the financialization of farming systems in the Canadian Prairie provinces. *The Journal of Peasant Studies, 42*(1), 119–144. https://doi.org/10.1080/03066150.2014.990894

Standing Committee on Agriculture and Agri-Food. (2018). *Toward a resilient Canadian agriculture and agri-food system: Adapting to climate change.* House of Commons. https://www.ourcommons.ca/Content/Committee/421/AGRI/Reports/RP9814809/agrirp11/agrirp11-e.pdf

Statistics Canada. (2017a). *Focus on Geography Series, 2016 Census.* https://www12.statcan.gc.ca/census-recensement/2016/as-sa/fogs-spg/Facts-can-eng.cfm?Lang=Eng&GK=CAN&GC=01&TOPIC=1

Statistics Canada. (2017b). *A portrait of a 21st century agricultural operation* (Farm and Farmer Operator Data). http://www.statcan.gc.ca/pub/95-640-x/2016001/article/14811-eng.htm.

Statistics Canada. (2017c). *2016 Census of Agriculture.* http://www.statcan.gc.ca/eng/ca2016.\

Statistics Canada. (2017d). *Number of farm operators by sex, age and paid non-farm work, historical data* (Table 32-10-0169-01). https://doi.org/10.25318/3210016901-eng

Statistics Canada. (2017e). *Farms classified by farm type* (Table 32-10-0403-01). https://doi.org/10.25318/3210040301-eng

Statistics Canada. (2018a, March 13). *Selected farm machinery, historical data* (Table 32-10-0163-01). https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210016301

Statistics Canada. (2018b, March 13). *Selected land management practices and tillage practices used to prepare land for seeding, historical data* (Table 32-10-0162-01). https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210016201

Statistics Canada. (2018c, April 30). *Manure and manure application methods in the year prior to the census* (Table 32-10-0410-01). https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210041001

Statistics Canada. (2018d, May 10). *Farm capital (farm machinery and equipment, livestock and poultry, land and buildings)* (Table 32-10-0437-01). https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210043701

Statistics Canada. (2019a, April 26). *Farms with a formal Environmental Farm Plan (EFP), Canada and provinces, 2017.* https://www150.statcan.gc.ca/n1/daily-quotidien/190426/t005b-eng.htm

Statistics Canada. (2019b, April 26). *The Daily—Farm management survey, 2017.* https://www150.statcan.gc.ca/n1/daily-quotidien/190426/dq190426b-eng.htm

Statistics Canada. (2019c). *Total area that received irrigation by crop type* (Table 38-10-0241-01). https://doi.org/10.25318/3810024101-eng

Statistics Canada. (2019d). *Agricultural water survey, 2018.* https://www150.statcan.gc.ca/n1/daily-quotidien/190912/dq190912d-eng.htm

Stinner, D. H., Stinner, B. R., & Martsolf, E. (1997). Biodiversity as an organizing principle in agroecosystem management: Case studies of holistic resource management practitioners in the USA. *Agriculture, Ecosystems & Environment, 62*(2–3), 199–213. https://doi.org/10.1016/S0167-8809(96)01135-8

Sudmeyer, R. A., Edward, A., Fazakerley, V., Simpkin, L., & Foster, I. (2016). *Climate change: Impacts and adaptation for agriculture in Western Australia* (Bulletin 4870). Department of Agriculture and Food. https://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1043&context=bulletins

Sylvester, G. (2019). *Blockchain for agriculture. Opportunities and challenges.* Food and Agriculture Organization of the United Nations & International Telecommunications Union. http://www.fao.org/3/CA2906EN/ca2906en.pdf

Szeto, K., Gysbers, P., Brimelow, J., & Stewart, R. (2014). The 2014 extreme flood on the southeastern Canadian Prairies in explaining extreme events of 2014 from a climate perspective. *Special Supplement to the Bulletin of the American Meteorological Society, 96*(12), S20–24. https://doi.org/10.1175/BAMS-D-15-00110.1

Szeto, K., Zhang, X., & White, R. E. (2016). The 2015 extreme drought in Western Canada. *Bulletin of the American Meteorological Society, 97*(12), S42–S46. https://doi.org/10.1175/BAMS-D-16-0147.1

Tarnoczi, T. J., & Berkes, F. (2009). Sources of information for farmers' adaptation practices in Canada's Prairie agro-ecosystem. *Climatic Change, 98*(1), 299. https://doi.org/10.1007/s10584-009-9762-4

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. (2020). A comprehensive quantification of global nitrous oxide sources and sinks. *Nature, 586*(7828), 248–256. https://doi.org/10.1038/s41586-020-2780-0

Toth, B., Corkal, D. R., Sauchyn, D., van der Kamp, G., & Pietroniro, E. (2009). The natural characteristics of the South Saskatchewan River Basin. In G. Marchildon (Ed.), *A dry oasis: Institutional adaptation to climate on the Canadian Plains* (pp. 95 –127). CPRC Press.

United Nations Environment Programme. (2020). *The emissions gap report 2020: A UN environment synthesis report.* http://www.unenvironment.org/emissions-gap-report-2020

United Nations Framework Convention on Climate Change. (2020, December 12). *Climate ambition summit builds momentum for COP26.* https://unfccc.int/news/climate-ambition-summit-builds-momentum-for-cop26

Unger, D. (January 16, 2020). *Lake St. Martin First Nation residents still waiting to go home after nine years.* CTV News. https://winnipeg.ctvnews.ca/lake-st-martin-first-nation-residents-still-waiting-to-go-home-after-nine-years-1.4771389

van Kooten, G. C. (2018). *Farm programs and agricultural support in Canada.* http://web.uvic.ca/~kooten/Agriculture/CanadaChapter.pdf

Venema, H. D., Oborne, B., & Neudoerffer, C. (2010). *The Manitoba challenge: Linking water and land management for climate adaptation.* International Institute for Sustainable Development. https://www.iisd.org/pdf/2009/the_manitoba_challenge.pdf

Waldick, R., Bizikova, L., White, D., & Lindsay, K. (2017). An integrated decision-support process for adaptation planning: Climate change as impetus for scenario planning in an agricultural region of Canada. *Regional Environmental Change, 17*(1), 187–200. https://doi.org/10.1007/s10113-016-0992-5

Walther, G., Roques, A., Hulme, P., Sykes, M., & Pyvsek, P. (2009). Alien species in a warmer world: Risks and opportunities. *Trends in Ecology & Evolution, 24,* 686–693.

Wang, S., Zhang, Y., Ju, W., Chen, J. M., Ciais, P., Cescatti, A., Sardans, J., Janssens, I. A., Wu, M., Berry, J. A., Campbell, E., Fernández-Martínez, M., Alkama, R., Sitch, S., Friedlingstein, P., Smith, W. K., Yuan, W., He, W., Lombardozzi, D., … Peñuelas, J. (2020). Recent global decline of CO_2 fertilization effects on vegetation photosynthesis. *Science, 370*(6522), 1295–1300. https://doi.org/10.1126/science.abb7772

Warner, K. D. (2008). Agroecology as participatory science: Emerging alternatives to technology transfer extension practice. *Science, Technology, & Human Values, 33*(6), 754–77.

Warren, F. & Lulham, N. (Eds.). (2021). *Canada in a changing climate: National issues.* Government of Canada. https://changingclimate.ca/site/assets/uploads/sites/3/2021/05/National-Issues-Report_Final_EN.pdf

Welton, G. (2010). *The impact of Russia's 2010 grain export ban.* Oxfam International. https://oi-files-d8-prod.s3.eu-west-2.amazonaws.com/s3fs-public/file_attachments/rr-impact-russias-grain-export-ban-280611-en_3.pdf

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., & David, C. (2009). Agroecology as a science, a movement and a practice: A review. *Agronomy for Sustainable Agriculture, 29,* 503–515. https://doi.org/10.1007/978-94-007-0394-0_3

Wheaton, E., Wittrock, V., Kulshreshtha, S., Koshida, G., Grant, C., Chipanshi, A. & Bonsal, B. (2005). *Lessons learned from the Canadian drought years of 2001 and 2002: Synthesis report.* Saskatchewan Research Council.

Wheaton, E., Kulshreshtha, S., Wittrock, V., & Koshida, G. (2008). Dry times: Hard lessons from the Canadian drought of 2001 and 2002. *The Canadian Geographer, 52*(2), 241–262. https://doi.org/10.1111/j.1541-0064.2008.00211.x

White-Crumney, A. (2019, April 11). Researcher says Saskatchewan's climate resilience report misses the point. *Regina Leader Post.* https://leaderpost.com/news/saskatchewan/sask-s-climate-resilience-report-shows-high-emissions-but-work-to-adapt

Wilson, A. (2017, August 10). *The new Canadian Agricultural Partnership: Dancing to the same old tune?* Food Secure Canada. https://foodsecurecanada.org/resources-news/news-media/new-canadian-agricultural-partnership-dancing-same-old-tune

Wilson, J., & James, I. (2021, August 16). Colorado River water shortage declared for first time; California could see cuts by 2024. *The Desert Sun.* https://www.desertsun.com/story/news/environment/2021/08/16/colorado-river-water-shortage-declared-california-could-face-cuts-2024/8155692002/

Wittrock, V., Halliday, R. A., Corkal, D. R., Johnston, M., Wheaton, E., Lettvenuk, J., Stewart, I., Bonsal, B., & Geremia, M. (2018). *Saskatchewan flood and natural hazard risk assessment.* https://www.saskatchewan.ca/-/media/news-release-backgrounders/2018/dec/saskatchewanfloodandnaturalhazardriskassessment-2.pdf

World Bank. (n.d.). *Fertilizer consumption (kilograms per hectare of arable land)*. https://data.worldbank.org/indicator/AG.CON.FERT.ZS?end=2018&start=1980

Woynillowicz, D., Beedell, E., & Wooders, P. (2021). *10 ways to win the global race to net-zero: Global insights to inform Canadian climate competitiveness.* International Institute for Sustainable Development. https://www.iisd.org/system/files/2021-05/10-ways-net-zero-canada-climate.pdf

Yarhi, E., & Regehr T. D. (2020). *Dominion Lands Act*. The Canadian Encyclopedia. https://www.thecanadianencyclopedia.ca/en/article/dominion-lands-policy

Yusa, A., Berry, P., Cheng, J. J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015). Climate change, drought and human health in Canada. *International Journal of Environmental Research and Public Health*, *12*(7), 8359–8412. https://doi.org/10.3390/ijerph120708359

Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent , L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G., & Kharin, V. V. (2019). Changes in temperature and precipitation across Canada. In E. Bush, & D. S. Lemmen (Eds.), *Canada's changing climate report* (pp. 112–193). Government of Canada. https://changingclimate.ca/site/assets/uploads/sites/2/2018/12/CCCR_Chapter4-Temperature-and-Precipitation-Across-Canada.pdf

Appendix A. Summary Table of Agriculture and Climate-Related Policies and Programs in Canada

Table A1. Federal government

Type	Policies and programs
Policy strategy and target-setting documents	• *Federal Sustainable Development Strategy (2019-2022)* and environmental indicators • *Food Policy for Canada* • *Barton Report* (Advisory Council on Economic Growth) • *Pan-Canadian Framework on Clean Growth & Climate Change* • *Canada's Implementation of the 2030 Agenda for Sustainable Development: Voluntary National Review* • United Nations Framework Convention on Climate Change (*Canada's NDC Submission to the UNFCCC*, *Canada's 7th National Communication 3rd Biennial Report*) and *Canada – National Targets* for the Convention on Biological Diversity.
Agriculture and Agri-Food Canada (AAFC) programs related to mitigation and climate resiliency	• Agricultural Climate Solutions (under the Natural Climate Solutions Fund) • Canadian Agricultural Partnership (to 2023) federal programs, including, among others, AgriScience, AgriInnovate, AgriAssurance, Agricultural Greenhouse Gases Program (ends 2021) • Canadian Agricultural Partnership cost-share programs, including Environmental Farm Plans (EFPs are now valid for 10 years only) and Business Risk Management programs • Canadian Agricultural Strategic Priorities Program • Value Chain Roundtables (includes focus on increasing sustainability for key products) • Agricultural Clean Technology Program • Living Laboratories Initiative • Food Policy initiatives, including the Food Waste Reduction Challenge

Type	Policies and programs
Non-AAFC programs related to mitigation and climate resiliency in agriculture	• Greenhouse Gas Pollution Pricing Act (fuel levy applies in all Prairie provinces; on-farm fuel is exempt) • Federal Greenhouse Gas Offset System (forthcoming, proposed publication of final regulations is fall 2021) • Clean Fuel Standard (proposed publication of final regulations is fall 2021) • Canada Water Agency (forthcoming) • Various climate change funding programs, including the Low Carbon Economy Fund (includes "supporting the forest and agriculture sectors to enhance stored carbon in forests and soils") and the Climate Action Fund (has funded some agriculture- and conservation-focused projects) • Disaster Mitigation and Adaptation Fund (large infrastructure only) • Canadian Centre for Climate Services • Innovative Solutions Canada
Conservation	• Ecological Gifts Program • Habitat Stewardship Programs for Species at Risk • Aboriginal Fund for Species at Risk • Lake Winnipeg Basin Program (for managing excessive nutrients)
Pesticides	• AAFC Pest Management Centre (Pest Control Products Act): Pesticide Risk Reduction Program and Minor Use Pesticide activities • Health Canada Pesticides and Pest Management: User Requested Minor Use Program, Pollinator Protection
Organic agriculture	• Canadian Organic Standards, Organic Standards Interpretation Committee • Safe Food for Canadians (has organic regulations) • Organics Value Chain Roundtable • Organic Science Cluster III

Source: Adapted from Food Secure Canada & FLEdGE, 2017.

Table A2. Manitoba (MB)

Name	Type	Short Description
Environmental Farm Plan	CAP Program	Administered by Keystone Agricultural Producers
Ag Action Manitoba Program for Farmers – Training and Consulting	CAP Program	Four focus areas including farm transition and farm risk management.
Ag Action Manitoba Program – Assurance: Environmental Best Management Practices	CAP Program	Grant to adopt actions recommended in EFPs. Cost-share program to incent farmers to adopt BMPs.
Ag Action Manitoba Program – Research and Innovation funding	CAP Program	Climate change, adaptation, and environmental sustainability are priority areas.
Ag Action Manitoba Program - Assurance: Ecological Goods and Services	CAP Program	Funds watershed districts to improve sustainable agri-environmental practices with producers.
Other Ag Action Manitoba programs	CAP Program	
Programming related to EG&S	Provincial programming	Includes Watershed EDG (part of Ag Action Manitoba), Riparian Tax Credit, Protected Areas Initiative, North American Waterfowl Management Plan, Prairie Habitat Joint Venture, Integrated Watershed Management Planning.
EG&S Initiative Working Group	Provincial programming	Established in 2009. Two key components: a MB government Policy Working Group and an external Stakeholder Knowledge Group
Energy efficiency and renewable programs	Provincial programming	Several small programs available through Efficiency Manitoba and Manitoba Hydro, some relevant for the agricultural sector.
Growing Outcomes in Watersheds (GROW, Jun 2019)	Provincial programming	Homegrown, provincewide CAD 5.2 million fund based on the successful Alternative Land Use Services (ALUS) model.

Name	Type	Short Description
Made-in-Manitoba Climate and Green Plan (2017) and Climate and Green Plan Implementation Act, 2018	Policy	First province in Canada to implement climate accountability legislation. Its legislation does not include long-term emissions reductions targets or a clearly-defined emissions reduction pathway.
Manitoba Protein Strategy	Policy	Strategy for investment attraction, processing and production, and sustainability.

Table A3. Saskatchewan (SK)

Name	Type	Short Description
Environmental Farm Plans	CAP Program	Administered by the province.
Pest Biosecurity Program	CAP Program	Program to increase resilience of crops to biosecurity threats, including through early detection and mitigation.
Farm Stewardship Program	CAP Program	Provides SK producers funding to implement beneficial management practices (BMPs) in three priority areas – water quality, climate change, and biodiversity.
Agri Environmental Technical Services	CAP Program	Producer-level support for the Farm Stewardship Program and FRWIP.
Farm and Ranch Water Infrastructure Program (FRWIP)	CAP Program	Program to support sustainable water sources for agriculture.
Irrigation Program	CAP Program	Funding support for irrigation projects.
Other CAP programs	CAP Program	Includes Canada and SK Community Pasture Transition Program, Assurance Systems Programs, and Agricultural Skills and Knowledge (ASK) program.
Agricultural Research Programs	Provincial programming	Various research and development activities.
BRACE program funding announcement (Apr 2019)	Provincial programming	Water-related adaptation program, part of Natural Resources Canada's BRACE program

Name	Type	Short Description
AgTech investment through Innovation Saskatchewan (August 2020)	Provincial programming	CAD 15 million investment program for agtech companies
Water Security Agency	Crown corporation	Runs several programs, including Agricultural Water Management Strategy and Flood Damage Prevention.
Energy efficiency and renewable programs	Provincial programming	Some small programs for energy efficiency assessments for residential users and small and medium-sized enterprises.
Prairie Resilience climate change strategy (2017)	Policy	For agriculture, focuses primarily on soil carbon sequestration.
Saskatchewan's Growth Plan 2030	Policy	30 goals and 20 actions for the 2020s to build a strong economy

Table A4. Alberta (AB)

Name	Type	Short Description
Environmental Farm Plan	CAP Program	Administered by the Agricultural Research and Extension Council of Alberta.
Environmental Stewardship and Climate Change – Producer	CAP Program	Supports producers in reducing negative impacts on the environment while enhancing sustainable production, managing climate change, and increasing profitability in the agriculture sector.
Farm Water Supply	CAP Program	Supports producers to improve their water supply security, including through BMPs. Helps producers create a Long-Term Water Management Plan.
Irrigation Efficiency	CAP Program	Assisting producers with the purchase of more efficient irrigation equipment and systems. Applicants must already have an approved Long-Term Water Management Plan.
Accelerating the Advancement of Agricultural Innovation and Adapting Innovative Solutions in Agriculture	CAP Program	Support activities that demonstrate the feasibility and potential for real world application of innovations.

Name	Type	Short Description
Other CAP programs	CAP Program	There are also programs on public agriculture literacy, youth education, agricultural training, assurance, and sustainability certifications, etc.
Agricultural Sustainability and Measurement	Provincial programming	Work with industry to measure impacts of the agri-food industry.
Strategic Research and Development Program	Provincial programming	Funding for basic and applied research initiatives, including for sustainable production.
Energy efficiency and renewable programs	Provincial programming	AB also has miscellaneous energy programs that are not agriculture-specific but could have implications for on-farm energy use. Alberta also has an offsets program and a Bioenergy Producer program.
Agriculture and Forestry Business Plan (2020)	Policy	Covers priority outcomes and initiatives to 2023 for the department.
Bill 7, Supporting Alberta's Local Food Sector Act (2018)	Policy	Aims to encourage the development and success of a local food sector and to regulate agricultural products (including organic products) within the province.

Table A5. Examples of other initiatives (regional, community)

Name	Type	Long Description
ALUS	Conservation	15 communities in AB, 3 communities in SK, 2 communities in MB.Provides annual payments to farmers and ranchers to produce ecological services on farmland.
Western Ranchlands Corporation	Conservation	"We are a conservation-minded agricultural investment and land management firm based in southwest Alberta, Canada… Western Ranchlands offers a new perspective and a new approach to synergistically combine the operation of livestock businesses, the conservation of open space, and real estate investment."
Rural Routes to Climate Solutions	On-farm practices	Partially funded by Government of Alberta. Partnerships with Stettler Learning Centre (also funded through GoA) and Organic Alberta.
Ducks Unlimited programs for private landowners	Conservation	Examples: Marginal Areas program (SK & MB only); Hay for Tender programs, Forage Program, Revolving Land Conservation Program and Wetland Restoration program (AB, SK, MB)
Saskatchewan Soil Conservation Association	On-farm practices	Example of a non-profit producer-based organization focused on sustainable/ conservation agriculture practices.
General Mills Regenerative Agriculture pledge	Industry-led	Pledge and pilot projects to advance regenerative agricultural practices on Prairie farms.

Published by the International Institute for Sustainable Development

Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700
Website: www.iisd.org
Twitter: @IISD_news

IISD

iisd.org