The Cost of Climate Change:

Food Production

By Ruiping Luo

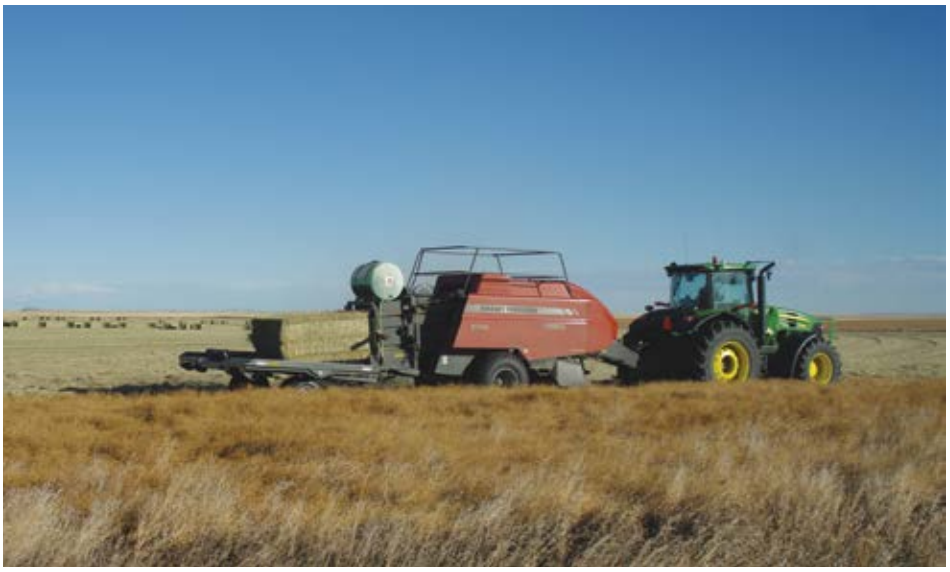
The world is undeniably warming, and in Canada's prairies, we are starting to feel the effects. According to Environment and Climate Change Canada (ECCC), Alberta has already warmed by 1.9°C since the mid-1900s – compared to an average global increase of 1°C — and is expected to continue warming at 2 to 3 times the global rate. With the rising temperatures, Alberta will experience changes in weather, impacting ecosystems, and those that rely on them. Forests and alpine habitats will shrink, and in a worst-case scenario, the southern grasslands could experience years of severe drought, becoming arid deserts.

For many Albertans, a noticeable effect will be in the cost of living, and one of the biggest impacts on household budgets is expected to be food. Agriculture is highly climate-sensitive, and a major factor that is believed to have influenced the development of agricultural societies was a stable climate. Wheat, a major Alberta crop and a staple in many households, is one of several immensely susceptible crops. The *2023 Statistics Canada Principle field crops* report expected Alberta to farm 8.0 million acres for wheat, and the province has produced an average 9,513,200 tonnes of wheat per year over the past 10 years, enough to feed a population more than twice that of Canada. Changes in wheat production, in Alberta and globally, will substantially affect food costs.

Crop growth in a warmer climate

Since industrialization, human activities have been the main cause of climate change, mostly through the burning of fossil fuels. We have also cut down forests, drained wetlands and converted grassland for agriculture, releasing carbon that had been stored in these ecosystems for hundreds or thousands of years. While there are many consequences to this human-caused climate change, some of the main effects will be increased atmospheric carbon, rising temperatures, and changes in weather.

Climate change will alter agriculture and food production in several ways. Elevated atmospheric carbon increases the rate of photosynthesis, allowing wheat and various other crops to grow larger and faster, an effect termed "carbon fertilization." In temperate regions, like Canada, warming is expected to increase the growth rates of crops, but also affect soil organisms and pests. Changes in rain and snow will affect water flow, impacting not only the water available to crops but also soil microbes, a community vital to crop health and nutrition. Altogether, a changing climate could have severe effects on water availability, nutrient content, and pest outbreaks in agricultural fields.



Agriculture is extremely sensitive to climate shifts. Climate change is likely to cause extreme weather events, degraded soils and more frequent pest outbreaks, endangering agriculture and food production. Photo © C. Olson

Impacts on water

Appropriate soil moisture conditions are crucial in wheat production, and agricultural soils may not adapt well to weather and precipitation changes. Under climate change models, Alberta is predicted to receive slightly more rain in an average year. However, rainfall will also become more extreme. Rather than light showers every few days, Alberta is expecting more heavy storms, with over 25 mm of water in 24 hours, followed by longer dry periods in between. Rainfall is also projected to be greater in spring and autumn, while summers could see less rain. For soils, this variation may be more damaging than beneficial.

Soils have a limited ability to store water. Less water is captured in soil from sudden, intense storms — as Alberta is expected to experience under climate change — than from a consistent light rain over several weeks. Especially with longer periods between rainfall events, soil moisture could be quickly

lost, increasing the risk of severe drought. This is especially true in summer, which is predicted to be hotter and drier with warming temperatures. Agricultural droughts might soon become commonplace, increasing the risk of crop failures and lowering production.

With more spring rain expected, flood risk is also higher. Soil water storage capacity can quickly be reached and exceeded during storms, and the resulting waterlogged soils lack the oxygen and nutrients required for crop growth. Remaining water is mostly lost as runoff, entering streams, and causing rivers to overflow. Floods damage crop roots and delay growth, as well as eroding and contaminating soils, impacting seeding and harvest. Such severe flooding could prove costly for agricultural yields.

Both drought and flood severity could be exacerbated by a reduction in snow. With warmer temperatures, Alberta is expected to receive less snow and more winter rain. Compared to rain, snow releases water more slowly. As a result, more snowmelt is captured and stored by soil, diminishing drought risk, and less snowmelt is lost as runoff. Snowmelt is also less likely to cause flooding than rain, and by remaining above soil, provides the soil with insulation against freezing winter temperatures. In contrast, rain can form a layer of ice within the soil, so that less water is able to enter, causing more severe floods. The loss of snowfall from climate change will likely worsen droughts and floods.

As well as weather patterns, climate change can affect soil characteristics, impacting the amount of water found in soil. Rising temperatures enhance rates of evaporation and transpiration — the exhaling of water by plants — which directly increases water loss from soil. Temperature also determines soil microbe activity, affecting soil organic matter (SOM) content and water storage. SOM, a component of soil made of decomposing plant and animal matter, is vital in water retention: in one acre, a one percent increase in SOM was calculated to hold up to 94.6 thousand litres more water. How quickly SOM is lost from soil largely depends on the activity of microbes and other decomposers, and warming is likely to increase the decomposition rate. As a result, SOM is lost faster, and soils with less SOM are less capable of holding water. So, warmer temperatures are likely to reduce the ability of soil to store water, increasing the risks of agricultural drought.

Alberta has two-thirds of Canada's irrigated land, and expanding irrigation has been proposed to reduce drought damage. Climate change will likely increase drought severity and place irrigation sources at risk. Photo © C. Olson

Irrigation has been publicized as a solution to anticipated droughts. Irrigated fields are less reliant on weather patterns for water, and irrigation can increase yield through the dry summer months. Except, climate change also places Alberta's rivers, the main water source for irrigation, at risk. With summers anticipated to be hotter and drier, high evaporation rates will lower water levels, reducing the water available for irrigation. Glacier meltwater, which contributes to summer flow in many of Alberta's rivers, will decline as glaciers recede. Over the next century, up to 90 percent of Alberta's glaciers could be lost, and an estimated one in four Albertans will experience water scarcity from the loss of glaciers. Expanding irrigation is not going to prevent drought if Alberta's rivers are dry.

Impacts on nutrients

Another way that climate change can impact the soil is through nutrient content. Warming increases microbe activity, as well as altering microbial communities and distribution. Since microbes play a vital role in nutrient cycling, through decomposing organic matter and weathering rocks to release essential nutrients, these changes could significantly modify soil nutrient availability.

Increased microbe activity will affect soil nutrients through faster decomposition and loss of soil organic matter. SOM, in addition to its water retention properties, absorbs and contains essential nutrients. These nutrients are slowly released as SOM decomposes. Nutrients not absorbed by roots or used by soil organisms are quickly lost, through surface runoff or leaching, where nutrients will be carried away by draining water. Since the ability of plant roots to absorb and use nutrients is limited, rapid decomposition could release nutrients too quickly for crops to use, increasing nutrient loss. As SOM declines under warming, the ability of soil to capture nutrients is also diminished, resulting in nutrient-poor soils.

Climate also affects nitrogen availability. Like most terrestrial plants, wheat growth is mainly limited by how much nitrogen it gets. Nitrogen input into soil is through fertilizer, decomposition of organic matter, and nitrogen fixation (converting nitrogen gas to reactive nitrogen compounds that plants can use). It can be lost from soil through processes like volatilization (the loss of nitrogen to the atmosphere as ammonia gas), leaching, and denitrification (conversion of reactive compounds into nitrogen gas). While it's not clear how nitrogen fixation and denitrification, both of which rely on microbial activity, would be impacted by a warming climate, the rate of volatilization is likely to increase since, like evaporation, this process increases in warm and dry conditions. Volatilization could especially increase during drought, thus reducing nitrogen in soil as the climate warms.

Runoff and leaching are also affected by climate. Both processes remove nitrogen and other nutrients from soil and are reliant on water flow. Runoff occurs when excess

water flows over the ground, causing soil erosion and washing nutrients into rivers and lakes. Leaching is when water enters soil and dissolves nutrients. These dissolved nutrients are carried downward as the water drains, beyond the reach of roots. More rain, especially heavy downpours, increases runoff and leaching, causing greater nutrient loss. Further, nutrient leaching can increase soil acidification, as alkaline or basic compounds are lost from soil. Acidic soils can decrease root growth, reduce microbial activity, and reduce the availability of nutrients. Very acidic soils can become toxic as heavy metals are released. The anticipated increase in heavy spring rains could prove very damaging for soil nutrients.

Lower soil nutrient content could decrease yield or reduce plant quality. Nutrient deficiency in wheat can cause stunted growth, yellowed leaves, and smaller or fewer kernels. It may also reduce plant nutrition. Cereal crops, like wheat, are an important source of minerals, and recent studies are finding that crop nutrition content is declining. One UK study found mineral content in wheat has declined 20 to 49 percent since the late 1900s, suggesting people will need to eat up to twice the amount to gain their essential minerals. The diminished nutrition in crops could be a result of less fertile soil, or due to faster growth, as increased carbon dioxide levels and extensive fertilizer use are allowing plants to grow larger and faster without incorporating as many proteins and minerals. For instance, crops grown under elevated carbon dioxide levels were found to contain 6 percent more carbon but 15 percent less nitrogen, implying crops will contain more sugars and less protein as carbon dioxide levels rise. In addition to reducing yield, climate change could reduce crop nutrition, increasing global malnutrition.

To compensate for soil nutrient depletion, artificial fertilizer use could increase, which is not a viable long-term solution to nutrient loss. That's because fertilizers, which have been shown to increase nutrient input and improve yield, come with negative repercussions. The most common fertilizers are for nitrogen, and on average, less than half of the nitrogen applied to fields is used by crops. The remainder is released into the atmosphere as nitrous oxide, a greenhouse gas over 250 times more potent than carbon dioxide, or washed into water sources, causing extensive damage to aquatic ecosystems. Excess fertilizer use also increases soil acidification, degrading soils and creating reliance on fertilizers.

Impacts on pests

Along with the impacts on water and nutrient availability, climate change could benefit pests. Insect pests are poikilotherms, meaning they cannot regulate their own body temperature and are particularly sensitive to heat. In temperate regions like Canada, warming is predicted to increase insect metabolism, allowing faster growth and development. As a result, insect pests can consume more, grow larger and become more abundant, potentially causing more frequent pest outbreaks and devastating crops. The UN Food and Agriculture Organization estimates up to 40 percent of food production is already lost to pests. Each additional degree of warming may cause a 10 to 25 percent increase in loss.

Rising temperatures may allow for range expansion of pests. Just as warming could open northern regions to agriculture, it can also encourage pest expansion into regions that were previously too cold. In China, wheat midge (*Sitodiplosis mosellana*), a major crop pest in Western Canada, has been estimated to have moved northward at nearly 60 kilometres per decade since 1950. Wheat midge have also been migrating north in Alberta, most recently reaching the Peace Region in 2011, and climate models for Canada predict both a continued northward expansion and a higher abundance of wheat midge as temperatures increase. Similarly, the invasive weed Santa Maria feverfew (*Parthenium hysterophorus*), a species known to cause wheat yield loss in the US, is likely to be facilitated by climate change and could expand into Canada if warming conditions persist. Local plants are unlikely to have resistance to new pests, and the expansion of pest ranges could cause extensive damage to susceptible crops.

Pests could also take advantage of climate-induced seasonal shifts. Warming is expected to raise winter temperatures, and this could increase pest populations since more pests that normally die in colder weather will survive. In many pests, temperature, and moisture are major determinants of emergence, arrival, or attack on host plants. With warmer and wetter springs, pests may emerge or arrive earlier, attacking younger and more vulnerable plants. For instance, aphid emergence and migration in Europe have advanced by roughly a month in the last few decades, leading to greater numbers when attacking crops. Earlier emergence and a longer growing season could also allow some pests to produce more generations per year, further increasing population size and crop destruction.

Many pests, especially invasive weeds, thrive on disturbance. Drought, flooding, and nutrient deficiency can stress crops, weakening crop defences. Flooding can also carry pest seeds, expanding the pests' range. In their stressed state, crops struggle to outcompete weeds, and weed establishment often aggravates the ramifications of flooding. Similarly, insect pests frequently take advantage of weakened defences to attack crops. For example, aphid outbreaks have been seen during droughts, when plant defences are low and physiological plant changes provide desirable feeding conditions for the pest. Climate change is expected to increase extreme weather, including drought and flooding, providing a benefit to pests.

As well, climate change is likely to reduce the efficiency of biological pest control. Most predators, parasitoids and other natural enemies used for pest control are also highly temperature sensitive. Even so, rising temperatures are expected to affect pests and their natural enemies differently. Since effective pest control relies on synchrony between pest and natural enemy development, even slight changes could disrupt interactions and release pests from natural controls. For instance, parasitoid wasps (*Tetrastichus julis*) are often used to control cereal leaf beetles (*Oulema melanopus*). During warmer springs, parasitoid wasps emerged earlier than cereal leaf beetles and were less effective at attacking leaf beetle larvae. Considering the widespread use of biological control in containing pest damage, disruption of this ecosystem service under climate change could be costly.

To counter increasing pest damage, producers often turn to pesticides. Pesticides, aside from toxicity to target pests, also harm a range of other organisms, including beneficial insects, birds, fish, reptiles, and mammals. Studies have shown that in 70.5 percent of

cases reviewed, pesticides harmed beneficial soil organisms. Pesticides can linger in the environment for years, polluting water, air, and soil, and producing and applying pesticides releases more greenhouse gases. Additionally, pests are continually evolving resistance to pesticides. Climate change is expected to increase pest populations, expand ranges, and induce rapid environmental changes — conditions that will encourage evolution and accelerate the development of pesticide resistance. As a result, new pesticides will need to be continually developed to keep pace with pest evolution. Expanding pesticide use could result in greater environmental harm than intended.

Benefits of climate change

There are some benefits climate change could bring to wheat production. In Canada, where agriculture is frequently limited by temperature, warming is expected to bring longer growing seasons, and carbon fertilization may encourage faster growth. Warming could also allow northward expansion of agriculture, with as much as 4.2 million square kilometres estimated to be farmable by 2080.

Despite this optimistic forecast, wheat production and agricultural expansion have several challenges and costs. Temperate wheat varieties are sensitive to heat stress, with most showing an optimal growing temperature between 15°C and 20°C. Plant breeders and geneticists are increasingly selecting for heat-tolerant varieties, though whether these varieties will survive in the extreme climatic conditions warming brings is still unknown. It's important to remember that expanding farmland to increase production has costs and can further contribute to global warming by releasing stored carbon. Agricultural conversion fragments and destroys native wildlife habitat and cropland is generally less diverse than native ecosystems, reducing local biodiversity and driving species decline. Fertilizer and pesticide applications contribute to the degradation of soil and can pollute nearby lands and waters. The loss of native grasslands, wetlands, and forests, which normally buffer against extreme weather events, increases flood and drought risk. While warming could bring some benefits to wheat production, these benefits seem far outweighed by the costs. Especially to those living in regions of the world most vulnerable to harm from climate-related impacts.

Economic costs of climate change

Climate change is expected to increase flooding and drought, lower soil nutrient content and cause greater pest damage. Proposed responses to these threats include irrigation expansion and increasing fertilizer and pesticide use. These management strategies, in addition to environmental costs, can be economically expensive.

According to the Government of Alberta, in 2021, Alberta had 612,223 hectares of irrigated land — worth over $3.7 billion — and aimed to expand to 625,000 hectares by 2025. These values fail to account for the water and electricity costs, which range from $12 to $25 per acre per year, totaling between $18 to $38 million per year. Nationally, 1.8 billion cubic metres of water were used to irrigate crops in 2020, and costs are likely to increase as water becomes scarce.

Costs of fertilizer and pesticides are also on the rise. Prices jumped an average of 80.2 percent for fertilizer cost in 2022, while pesticides rose at a slower 7.7 percent. Farm Credit Canada estimated fertilizer sales totaled $10.1 billion, with an additional $3.3 billion in agricultural chemicals, including pesticides. These costs are expected to increase by five percent or greater in 2023.

Higher production costs are already inflating bread and flour prices. In March 2022, Canadians paid an average 13.5 percent more for bread than the previous year. While some of this cost was attributed to global events, such as Russia's invasion of Ukraine, causing uncertainty in the wheat market, some of it was linked to production costs. Statistics Canada reports that the price of grain rose 65.1 percent, with agricultural chemicals, such as pesticides and fertilizers, increasing 33.9 percent. In addition, drought conditions in the prairies severely lowered yield, causing a 37.1 percent decline in Canadian wheat production compared to the previous year. As drought becomes more frequent and severe, and as fertilizer and pesticide application increases to compensate for warming-induced changes, the costs of bread and other foods can only grow.

We are already experiencing the consequences of climate change, and these costs will worsen as global warming continues. At the current rate of emissions, the world could exceed 1.5°C of warming in the next five years. Even if all greenhouse gas emissions stop immediately, there is still a high chance of overshooting 1.5°C. Still, a cease in emissions would maintain global temperatures below 2°C of warming — a level associated with global crop failures and widespread famine — and 2°C is preferable to 4°C, a threshold with potentially catastrophic consequences for life on Earth. We need to act now to prevent these costs from becoming greater.

Wetlands and native habitats are vital buffers against drought, flooding and other extreme weather events. Agricultural expansion often fragments and devastates important habitats, increasing drought and floods.
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