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Climate Change Impacts and Adaptation:
A Canadian Perspective

Agriculture

Prepared by the Climate Change Impacts and Adaptation Directorate
Natural Resources Canada
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Taking action on climate change
Together we can do it.

Canada

Preface

There is strong consensus in the international scientific community that climate change is occurring and that the impacts are already being felt in some regions (see, for example, the recent Third Assessment Report of the Intergovernmental Panel on Climate Change). It is also widely accepted that even after introducing significant measures to reduce greenhouse gas emissions, some additional degree of climate change is inevitable, and this will have significant economic, social and environmental impacts on Canada and Canadians.

It is possible to reduce our vulnerability to climate change. An effective response involves both the reduction of greenhouse gas emissions as well as adaptation to the impacts resulting from a changing climate. Reducing greenhouse gas emissions will decrease both the amount of climate change, as well as the rate of change, so that effective adaptation can occur. Adaptation refers to activities that minimize the negative impacts of climate change, and position us to take advantage of new opportunities that may be presented.

This chapter is part of the report *"Climate Change Impacts and Adaptation: a Canadian Perspective"*. The report includes a series of chapters that present brief summaries of impacts and adaptation research published over the past five years related to key sectors within Canada. Results of research supported by the Government of Canada's Climate Change Action Fund (CCAF) are highlighted in boxes within each chapter of the report.

The agriculture chapter largely focuses on the impacts of climate change on primary agricultural production in Canada, potential adaptation options, and vulnerability of agriculture at the farm level. While this chapter considers only agricultural issues, it must be recognized that climate change impacts as well as adaptation decisions in the agriculture sector will be influenced by, and have implications for, other sectors (e.g. water resources, communities). As such, a complete assessment of impacts and adaptation options will have to take into consideration issues raised within other chapters of this report.

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"Agriculture is inherently sensitive to climate... Without adaptation, climate change is generally problematic for agricultural production and for agricultural economies and communities; but with adaptation, vulnerability can be reduced..."(1)

In 1998, the Canadian agriculture and agri-food industry generated approximately $95 billion in domestic revenue, and was the third largest employer in the country.[2, 3] Canada's agri-food exports in 2000 were valued at $23.4 billion, accounting for 6.1% of total merchandise exports.[3] Farming operations are spread across Canada, with the greatest area of farmland located in the Prairie Provinces (Table 1). Cattle and dairy farms account for the highest amounts of farm cash receipts, although wheat, canola, and other cereals and oilseeds are also important contributors.[4] Although agriculture is a vital component of the Canadian economy, only a small percentage of our country is actually farmed. Due to limitations imposed primarily by climate and soils, just 7% of Canada's landmass is used for agricultural purposes.[5] Climate is also a strong control on the variation in year-to-year production. For example, the drought that plagued much of Canada during

TABLE 1: Distribution of farms across Canada.[4]

REGION	NO. OF FARMS*	TOTAL AREA OF FARMS (ha)	MAIN TYPES OF FARM
Canada	230,540	67,502,446	Cattle (beef), grain and oilseed
Newfoundland and Labrador	519	40,578	Misc. specialty, vegetable
Prince Edward Island	1,739	261,482	Cattle (beef), field crop
Nova Scotia	3,318	407,046	Misc. specialty, fruit
New Brunswick	2,563	388,053	Cattle (beef), misc. specialty
Quebec	30,539	3,417,026	Cattle (dairy), misc. specialty
Ontario	55,092	5,466,233	Cattle (beef), grain and oilseed
Manitoba	19,818	7,601,772	Cattle (beef), grain and oilseed
Saskatchewan	48,990	26,265,645	Wheat, grain and oilseed
Alberta	50,580	21,067,486	Cattle (beef), grain and oilseed
British Columbia	17,382	2,587,118	Misc. specialty, cattle (beef)

* with receipts over $2499

2001 seriously impacted farm operations. Water shortages and heat stress in some regions of Saskatchewan and Alberta have significantly lowered crop yields and threatened the availability of feed and water for livestock.[6] Some other impacts of the 2001 drought are listed in Table 2. In certain areas of the Prairies, 2001 was part of a multiyear drought that extended into the summer of 2002.

Many believe that the consequences of the 2001 drought may be indicative of what the agriculture sector in Canada can expect more frequently in the future. Climate change could lead to more extreme weather conditions, increases in pest problems, and severe water shortages. On the other hand, a warmer climate and longer growing season could benefit many aspects of Canadian agriculture. In general, experts agree that future climate changes of the magnitude projected by the Intergovernmental Panel on Climate Change[8] would result in both advantages and disadvantages for the agricultural sector in Canada, and that the impacts would vary on a regional basis.

A key factor in determining the magnitude of climate change impacts on agriculture is adaptation. Appropriate adaptations would allow agriculture to minimize losses by reducing negative impacts, and maximize profits through capitalizing on the benefits. There are many different adaptation options available to the agricultural sector, which vary greatly in their application and approach. Selecting and implementing adaptation strategies will require consideration of the physical, socio-economic and political influences on agriculture, as well as the contributing roles of producers, industry and government. It is also necessary to recognize that climate change is just one of many challenges facing the agricultural sector, and that it may not be considered a short-term priority in decision making.

This chapter examines recent research on climate change impacts and adaptation in the Canadian agricultural sector, focusing on primary production and the vulnerability of agriculture at the farm level. The potential impacts of climate change on the agri-food industry and possible adaptation options, although extremely important, are not addressed comprehensively, as these topics remain poorly investigated and only limited published information is available.

TABLE 2: Impacts of the 2001 drought on agriculture.[6, 7]

REGION	
British Columbia	• Losses in vegetable crops • Negative effects on forage crops, especially in northern Okanagan
Prairies	• Wheat and canola production down 43% from 2000 • Impact of decreased grain production estimated at $5 billion • Water for irrigation in spring rationed in Alberta for first time • In Manitoba, increased disease problems in canola, barley and wheat
Great Lakes–St. Lawrence	• Most crops in Ontario impacted by dry weather and heat • Increased stress from disease, insects and hail • Record numbers of certain insects in Quebec
Atlantic	• Potato harvest in P.E.I. down 35–45% • Fruit (e.g., blueberries, strawberries) and other vegetable (e.g., beans) crops impacted by drought stress

Previous Work

"Global climatic changes will in all likelihood result in both positive and negative impacts on Canadian agriculture."[9]

In their summary of Canadian research as part of the Canada Country Study, Brklacich et al.[9] stated that climate change will have a wide range of impacts on agriculture in Canada. Most regions of the country are expected to experience warmer conditions, longer frost-free seasons and increased evapotranspiration. The actual impacts of these changes on agricultural operations, however, will vary depending on factors such as precipitation changes, soil conditions and land use. In general, northern agricultural regions are expected to benefit most from longer and warmer frost-free seasons. Some northern locations (e.g., Peace River region of Alberta and British Columbia, and parts of northern Ontario and Quebec) may also experience new opportunities for cultivation, although the benefits will likely be restricted to areas south of latitude 60°N for the next several decades. Poor soil conditions will be a major factor limiting the northward expansion of agricultural crops. In southern Ontario and Quebec, warmer conditions may increase the potential for the growth of specialty crops, such as apples.

In many cases, the positive and negative impacts of climate change would tend to offset each other. For instance, the positive impacts of warmer temperatures and enhanced CO_2 on crop growth are expected to largely offset the negative impacts of increased moisture stress and accelerated crop maturation time. It should be noted that these predictions are characterized by a high degree of uncertainty and do not include potential changes in pest and pathogen outbreaks (e.g., warmer winters may increase grasshopper infestations in the Prairies), nor do they consider the potential impacts of agricultural land fragmentation.

Agricultural adaptation to climate change was considered a relatively new field of study at the time of the Canada Country Study. The majority of adaptation research focused on identifying adaptation options and assessing their feasibility. These studies were mainly technical in nature, and did not consider economic practicalities or the capacity of producers to undertake the adaptation. To address this, Brklacich et al.[9] recommended increasing the farming community's involvement in adaptation research.

Impacts on Agriculture

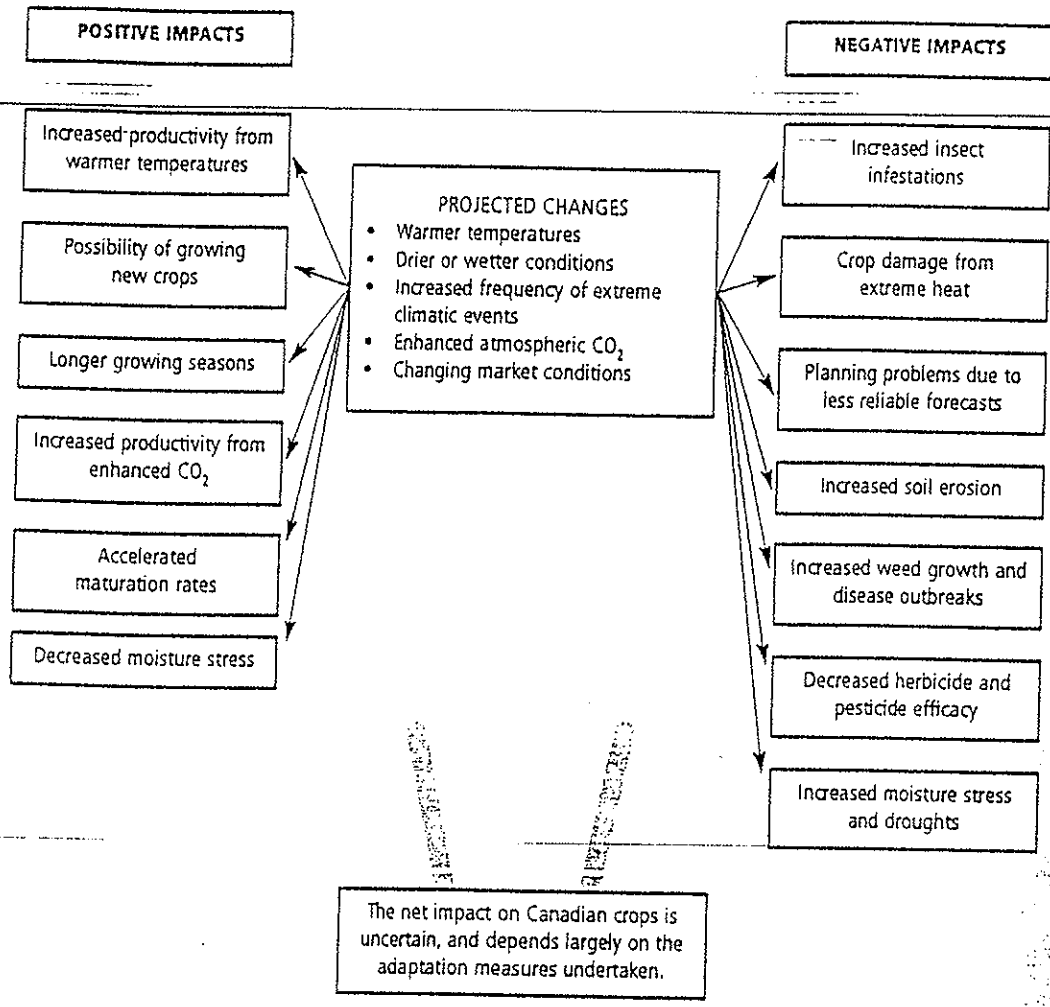
"Climate change will impact agriculture by causing damage and gain at scales ranging from individual plants or animals to global trade networks."[10]

Impacts on Crops

Climate change will potentially have many impacts on agricultural production (Figure 1). As such, there is great variation in projections of crop response to climate change, with both gains and losses commonly predicted. Several recent Canadian studies have integrated crop models with general circulation model (GCM) output for a $2xCO_2$ climate scenario, in order to project the impact of climate change on different types of crops. Examples include:

- McGinn et al.[11], who suggested that yields of canola, corn and wheat in Alberta would increase between 21 and 124%.
- Singh et al.[12], who suggested that corn and sorghum yields in Quebec could increase by 20%, whereas wheat and soybean yields could decline by 20-30%. Canola, sunflowers, potatoes, tobacco and sugarbeets are expected to benefit, while a decrease in yields is anticipated for green peas, onions, tomatoes and cabbage.
- Bootsma et al.[13], who suggested that there could be an increase in grain corn and soybean yields in the Atlantic Provinces by 3.8 and 1.0 tonnes/hectare respectively, whereas barley yields are not expected to experience significant changes. They further suggested that a minimum of 50% of the agricultural land area presently seeded to small grain cereals and silage corn may shift production to grain corn and soybeans to maximize economic gains.

FIGURE 1: Potential impacts of climate change on agricultural crops in Canada.



As with other sectors, concerns exist about the resolution of GCM output when modelling agricultural impacts (e.g., reference 12). Many studies interpolate GCM data to obtain regional projections of future changes in climate. Questions have been raised about the validity of the interpolation methods and the accuracy of the results, especially for regions with specific microclimates (e.g., Niagara Penisula, Annapolis Valley). With respect to methodology, however, a recent statistical study concluded that differences in the downscaling methods used to address scale issues do not unduly influence study results,[14] thereby increasing general confidence in model projections.

Increased moisture stress and drought are major concerns for both irrigated and non-irrigated crops across the country. If adequate water is not available, production declines and entire harvests can be lost. While climate change is expected to cause moisture patterns to shift, there is still considerable uncertainty concerning the magnitude and direction of such changes. Furthermore, longer growing seasons and higher temperatures would be expected to increase demand for water, as would changes in the frequency of drought. Boxes 1 and 2 describe the results of recent studies that examined how climate change may affect moisture conditions in the Prairies and the Okanagan Valley, two of the driest agricultural regions of Canada.

BOX 1: Will the Prairies become drier? [15, 16]

Will moisture deficits and drought increase in the future due to climate change? This is a key question for the Prairie Provinces, where moisture constraints are already a large concern and recurrent drought results in substantial economic losses in the agricultural community. Unfortunately, a clear answer to this question remains elusive.

Using the Canadian Centre for Climate Modelling and Analysis coupled General Circulation Model (CGCM1), Nyirfa and Harron [16] found that moisture limitations would be significantly higher over much of the Prairies' agricultural regions by 2040–2069. Although precipitation is expected to increase, it will not be sufficient to offset increased moisture losses from warmer temperatures and increased rates of evapotranspiration. As a result, the researchers believe that spring-seeded small grain crops will be threatened unless adaptations, such as cropping changes and shifts in pasture areas, are undertaken.

In contrast, using a range of climate change scenarios, McGinn et al. [15] found that moisture levels in the top 120 cm of the soil profile would be the same or higher than present-day values. Their models also suggested that the seeding dates for spring wheat will be advanced by 18–26 days, and that the growing season will be accelerated. This would allow crops to be harvested earlier in the year, thereby avoiding the arid conditions of late summer. However, the benefits are not expected to be felt evenly across the Prairies; there are regions of concern, such as southeastern Saskatchewan and southern Manitoba, where summer precipitation is projected to decrease.

BOX 2: Water supply and demand in the Okanagan [17]

Agricultural viability in the southern Okanagan Valley is greatly influenced by the availability of irrigation water. The researchers project that crop water demands and irrigation requirements will increase by more than 35% from historic values by the latter part of the present century. While the main lake and channel are expected to contain enough water to meet these rising demands, agricultural operations dependent on tributary flow will likely experience water shortages.

To deal with future water supply-demand mismatches, Neilsen et al. [17] advocate increased use of water conservation measures, such as micro-irrigation and applying soil mulches. They also suggested that new techniques, including regulated deficit irrigation and partial root zone drying, would yield substantial water savings.

(Photo: Stewart Cohen, 2001)

While there remain considerable uncertainties regarding the nature of future climate changes at the regional and local scales, there is no question that the level of carbon dioxide in the atmosphere will continue to increase for several decades. Enhanced atmospheric CO_2 concentrations have generally been found to increase crop production. This is because higher CO_2 levels tend to improve plant water-use efficiency and rates of photosynthesis. However, the relationship is not simple. For instance, certain types of plants, such as legumes, are expected to benefit more in the future than others, and the nutritional quality of some crops will likely decline. In addition, there are several factors, including moisture conditions and the availability of soil nutrients, that could limit or negate the benefits of CO_2 fertilization on plant growth. Although some impact studies do attempt to incorporate CO_2 effects into their modelling, many researchers feel that there are too many uncertainties to effectively integrate the effects of increased atmospheric CO_2.[12]

Another complicating factor in projecting future trends in crop yields is the interaction of climatic changes and enhanced CO_2 concentrations with other environmental stresses, such as ozone and UV-B radiation. For example, warmer temperatures tend to increase ground-level ozone concentrations, which, in turn, negatively affect crop production. Studies have suggested that the detrimental effects of enhanced ozone concentrations on crop yields may offset any gains in productivity that result from increased atmospheric CO_2 levels.[18]

Changing winter conditions would also significantly impact crop productivity and growth. Climate models project that future warming will be greatest during the winter months. With warmer winters, the risk of damage to tree fruit and grape rootstocks will decline substantially in areas such as the southern Okanagan Valley.[17] However, warmer winters are also expected to create problems for agriculture, especially with respect to pests, because extreme winter cold is often critical for controlling populations. Warmer winters may also affect the resilience of crops (*see* Box 3).

Many crops may be more sensitive to changes in the frequency of extreme temperatures than to changes in mean conditions. For example, an extreme hot spell at the critical stage of crop development has been shown to decrease the final yields of annual seed crops (e.g., reference 20) and damage tree fruit such as apples[17]. Crops that require several years to establish (e.g., fruit trees) are especially sensitive to extreme events. To date, however, most impact studies have focused on changes in mean conditions, with scenarios of extreme climate events only now being developed. Many experts believe that an increase in the frequency and intensity of extreme events would be the greatest challenge facing the agricultural industry as a result of climate change.

Another factor not usually included in modelling of climate change impacts is future changes in wind patterns, mainly because wind projections from GCMs are highly uncertain[21] and wind phenomena, in general, are poorly understood. However, wind is clearly an important control on agricultural production, which strongly influences evapotranspiration and soil erosion, especially on the Prairies. As such, exclusion of future wind dynamics increases the uncertainty in assessments of climate change impacts.

Another important consideration for crop production is the observation that recent warming has been asymmetric, with night-time minimums increasing more rapidly than daytime maximums. Climate models project that this trend will continue in the future. This type of asymmetric warming tends to reduce crop water loss from evapotranspiration and improve water use efficiency.[22] Under such conditions, climate change impacts on crop productivity may be less severe than the impacts predicted assuming equal day and night warming.[23]

BOX 3: Would warmer winters benefit crops?[19]

Although harsh winters are a constraint to the distribution of perennial crops, warmer winters are not necessarily beneficial. In fact, winter damage to perennial forage crops could actually increase in eastern Canada, due to reduced cold hardening during the fall, an increase in the frequency of winter thaw events, and a decrease in protective snow cover. For example, by 2040–2069, despite an increase in annual minimum temperatures of almost 5°C, the number of cold days (below -15°C) without a protective snow cover (>0.1 m depth) could increase by more than two weeks.

Conversely, fruit trees are expected to benefit from a decreased risk of winter damage. This is because milder winter temperatures would reduce cold stress, while a decrease in late spring frosts would lower the risk of bud damage in many regions. However, an increase in winter thaw events would decrease the hardiness of the trees, and increase their sensitivity to cold temperatures in late winter.

Impacts on Livestock

There are more than 90,000 livestock operations in Canada, which accounted for more than $17 billion in farm cash receipts in 2000.[4] Despite the economic importance of livestock operations to Canada, relatively few studies have examined how they could be impacted by climate change.

Temperature is generally considered to be the most important bioclimatic factor for livestock.[24] Warmer temperatures are expected to present both benefits and challenges to livestock operations. Benefits would be particularly evident during winter, when warmer weather lowers feed requirements, increases survival of the young, and reduces energy costs.[25] Challenges would increase during the summer, however, when heat waves can kill animals. For example, large numbers of chicken deaths are commonly reported in the United States during heat waves.[26, 27] Heat stress also adversely affects milk production, meat quality and dairy cow reproduction.[24] In addition, warmer summer temperatures have been shown to suppress appetites in livestock and hence reduce weight gain.[28] For example, a study conducted in Appalachia found that a 5°C increase in mean summer temperature caused a 10% decrease in cow/calf and dairy operations.[28]

Provided there is adequate moisture, warmer temperatures and elevated CO_2 concentrations are generally expected to increase growth rates in grasslands and pastures.[29, 30, 31] It is estimated that a doubling of atmospheric CO_2 would increase grassland productivity by an average of 17%,[29] with greater increases projected for colder regions[32] and moisture-limited grassland systems.[29] However, study results tend to vary greatly with location, and changes in species composition may affect the actual impacts on livestock grazing.[29] For instance, studies have noted future climate changes, particularly extreme events, may promote the invasion of alien species into grasslands,[33] which could reduce the nutritional quality of the grass.

An increase in severe moisture deficits due to drought may require producers to reduce their stock of grazing cattle to preserve their land, as exemplified by the drought of 2001 when many Prairie producers had to cull their herds. For the 2002 season, it was predicted that many pastures would be unable to support any grazing, while others would be reduced to 20-30% of normal herd capacity.[34]

There is relatively little literature available on the impacts of extreme climate events on livestock. Nevertheless, storms, blizzards and droughts are an important concern for livestock operations.[28] In addition to the direct effects on animals, storms may result in power outages that can devastate farms that are heavily dependent upon electricity for daily operations. This was exemplified by the 1998 ice storm in eastern Ontario and southern Quebec, when the lack of power left many dairy farms unable to use their milking machines. This threatened the health of the cows (due to potential mastitis) and caused significant revenue losses.[35] Milk revenue was also lost through the inability to store the milk at the proper temperature. Furthermore, the lack of electricity made it difficult to provide adequate barn ventilation and heating, thereby making the animals more susceptible to illness.[35]

Soil Degradation

"Soil degradation emerges as one of the major challenges for global agriculture. It is induced via erosion, chemical depletion, water saturation, and solute accumulation."[10]

Climate change may impact agricultural soil quality through changes in soil carbon content, nutrient leaching and runoff. For example, changes in atmospheric CO_2 concentrations, shifts in vegetation and changes in drying/rewetting cycles would all affect soil carbon, and therefore soil quality and productivity.[36, 37]

Soil erosion threatens agricultural productivity and sustainability, and adversely affects air and water quality.[38] There are several ways that soil erosion could increase in the future due to climate change. Wind and water erosion of agricultural soils are strongly tied to extreme climatic events, such as drought and flooding, which are commonly projected to increase as a result of climate change.[39, 21] Land use change could exacerbate these impacts, as conversion of natural vegetation cover cropland greatly increases the sensitivity of the landscape to erosion from drought and other climatic fluctuations.[40] Warmer winters may result in a decrease in protective snow cover, which would increase the exposure of soils to wind erosion, whereas an increase in the frequency of freeze-thaw cycles would enhance the breakdown of soil particles.[41] The risk of soil erosion would also increase if producers respond to drought conditions through increased use of tillage summerfallow.

Pests and Weeds

Weeds, insects and diseases are all sensitive to temperature and moisture,[42] and some organisms are also receptive to atmospheric CO_2 concentrations.[43, 44] Therefore, understanding how climate change will affect pests, pathogens and weeds is a critically important component of impact assessments of climate change on agriculture.

Most studies of climate change impacts on weeds, insects and diseases state a range of possible outcomes, and have been generally based on expert opinion rather than results of field- or lab-based research experiments. Conclusions from these studies include the following:

- Elevated CO_2 concentration may increase weed growth.[42]
- Livestock pests and pathogens may migrate north as the frost line shifts northward.[28]
- The probability of year-to-year virus survival may increase.[45]
- Warmer winters may increase the range and severity of insect and disease infestations.[42]
- Longer and warmer summers may cause more frequent outbreaks of pests, such as the Colorado potato beetle.[46]
- Pathogen development rate and host resistance may change.[47]
- Geographic distribution of plant diseases may change.[48]
- Competitive interactions between weeds and crops may be affected.[49]

Studies are needed to test and validate these predictions, and the results must be better incorporated into impact assessments.[50]

Significant work has been completed on the climatic controls on grasshopper populations in Alberta and Saskatchewan.[51] This research has shown that grasshopper reproduction and survival are enhanced by warm and dry conditions. For example, warm and dry weather in 2001 was associated with a 50% increase in the average number of adult grasshoppers per square metre, compared to values in 2000. Above-average temperatures increase the development and maturation of grasshoppers, and allow them to lay more eggs before the onset of frost. Mild winters also benefit grasshopper populations because extreme cold temperatures can kill overwintering eggs.[51] An increase in temperature and drought conditions in the Prairies, as projected by climate models,[52] could lead to more intense and widespread grasshopper infestations in the future.

Recent work indicates that the relationships between elevated atmospheric CO_2 concentrations, warmer temperatures and pest species are complex. An example is a study of the impacts on aphids,[43] serious pests that stunt plant growth and deform leaves, flowers and buds. Although elevated CO_2 concentrations enhanced aphid reproduction rates, they also made the aphids more vulnerable to natural enemies by decreasing the amount of an alarm pheromone. This suggests that aphids may in fact become less successful in an enhanced CO_2 environment.[43]

Invasive species, such as weeds, are extremely adaptable to a changing climate, as illustrated by their presently large latitudinal ranges. Invasive species also tend to have rapid dispersal characteristics, which allow them to shift ranges quickly in response to changing climates. As a result, these species could become more dominant in many areas under changing climate conditions.[44]

It is also expected that climate change would decrease pesticide efficacy, which would necessitate changes to disease forecasting models and disease management strategies.[48, 49] This could involve heavier and more frequent applications, with potential threats to non-target organisms and increased water pollution,[49] as well as increased costs associated with pesticide use.[53] Similar trends are predicted for herbicide use and costs in the future.[54]

Economic Impacts

Assessing the economic impacts of climate change on agriculture generally involves the use of a variety of tools, including climate, crop and economic models. Each step in the modelling process requires that assumptions be made, with the result that final outputs are limited by cascading uncertainties.[25] It is therefore not surprising that agricultural economic impact assessments in Canada are characterized by great variability.[55] On a general level, however, the economic impacts of climate change are expected to mirror the biophysical impacts (e.g., economic benefits are predicted where effects on crop yields are positive). Studies suggest that Canadian agriculture should generally benefit from modest warming.[23]

It must be noted, however, that most economic impact assessments do not consider changes in the frequency and severity of extreme events. The sensitivity of agriculture to extreme events, as noted previously, suggests that overall economic losses could be more severe than commonly projected. For instance, the 1988 drought caused an estimated $4 billion in export losses,[56] and the 2001 drought is expected to result in record payouts from crop insurance programs of $1.1 to 1.4 billion.[6] Economic impact studies also tend to aggregate large regions, and generally do not acknowledge the impacts on specific farm types and communities.[55]

International markets will also play a significant role in determining the economic impacts of climate change on the Canadian agricultural sector. In fact, changes in other countries could have as much influence on Canadian agriculture as domestic changes in production.[9] North American agriculture plays a significant role in world food production and, since Canada is generally expected to fare better than many other countries with respect to the impacts of climate change, international markets may favour the Canadian economy. Trade agreements, such as NAFTA and GATT, are also likely to affect Canadian agriculture;[57] however, quantitative studies of these issues are generally lacking.

Agricultural Adaptation to Climate Change

"The agriculture sector historically has shown enormous capacity to adjust to social and environmental stimuli that are analogous to climate stimuli." [10]

To assess the vulnerability of agriculture to climate change, it is necessary to consider the role of adaptation. Appropriate adaptations can greatly reduce the magnitude of the impacts of climate change (*see* Box 4). Assessment of adaptation options must consider six key questions:[25, 55, 58, 59]

- To what climate variables is agriculture most sensitive?
- Who needs to adapt (e.g., producers, consumers, industry)?
- Which adaptation options are worth promoting or undertaking?
- What is the likelihood that the adaptation would be implemented?
- Who will bear the financial costs?
- How will the adaptation affect culture and livelihoods?

BOX 4: How does adaptation affect impact assessments? [60]

When adaptation measures were incorporated directly into impact assessments, the impacts of climate change on crop yields were found to be minimal in agricultural regions across Canada. In fact, yields of many crops, including soybeans, potatoes and winter wheat, were projected to increase under a 2xCO_2 scenario. Some adaptation options considered in the study included using nitrogen fertilization to offset the negative impacts of increased water stress on spring wheat, and advancing the planting dates of barley.

It is also important to understand how adaptation to climate change fits within larger decision-making processes.[61] Climate change itself is unlikely to be a major control on adaptation; instead, decision making by producers will continue to be driven jointly by changes in market conditions and policies.

Adaptation Options

Adaptation options can be classified into the following categories:

- Technological developments (e.g., new crop varieties, water management innovations).
- Government programs and insurance (e.g., agricultural subsidies, private insurance).
- Farm production practices (e.g., crop diversification, irrigation).
- Farm financial management (e.g., crop shares, income stabilization programs).[1]

> **BOX 5: Evaluating adaptation options [62]**
>
> The applicability and success of different adaptation options will vary greatly between regions and farm types. To determine whether an adaptation option is appropriate for a given situation, its effectiveness, economic feasibility, flexibility, and institutional compatibility should be assessed. In addition, the characteristics of the producer and the farm operation should be considered, as should the nature of the climate change stimuli. Possible economic and political constraints are also important considerations.
>
> Most importantly, however, the adaptation option should be assessed in the context of a broader decision-making process. Researchers agree that agriculture will adapt to climate change through ongoing management decisions, and that the interactions between climatic and non-climatic drivers, rather than climate change alone, will direct adaptation.

These adaptations could be implemented by a number of different groups, including individual producers, government organizations, and the agri-food industry.[1] These groups have differing interests and priorities, which may at times conflict. Therefore, before determining which adaptation options should be promoted or implemented, they should be carefully and thoroughly assessed (*see* Box 5).

Much of the adaptation research in agriculture has focused on water shortages. Common suggestions for addressing water-related concerns include improving irrigation systems and adjusting the selection of planting dates and cultivars.[60, 61] For instance, longer and warmer growing seasons may allow earlier planting and harvesting dates, so that the extremely arid conditions of late summer are avoided. To deal with historic water shortages in southern Alberta, irrigation canals were upgraded, water storage capacity was increased, and irrigation management was improved.[63] These strategies, along with water transfers and changes to crop insurance programs, are adaptation options often suggested for dealing with future climate changes.

Water conservation measures are another important adaptation mechanism for agriculture. For example, snow management could be used to increase water storage,[64] while equipment maintenance and upkeep could help to reduce water waste.[62] The use of summerfallow may be necessary for dryland farmers in areas of recurrent drought, but use of minimum tillage and chemical fallow techniques offer significant advantages over tillage summerfallowing with respect to soil erosion and retention of organic carbon in the soil.[65]

New species and hybrids could play an important role in agricultural adaptation. Development of new heat- and drought-resistant crop varieties is a frequently recommended adaptation option. Improving the adaptability of agricultural species to climate and pests is an important component of the research being conducted at federal, provincial, university and industrial organizations.[3] The potential role of biotechnology and soil organisms in enhancing the resilience of soils and plants is also being investigated.[3]

In eastern Canada, the fruit tree sector is expected to benefit from the introduction of new cultivars and species[19] and, in the southern Okanagan Basin, a longer growing season would allow new fruit varieties to be grown.[17] In the Atlantic Provinces, researchers predict that corn and soybeans will increase in dominance, and that corn hybrids commonly used today in southern Ontario will be introduced to take advantage of warmer temperatures (*see* Box 6).

There is general optimism regarding the ability of livestock operations to adapt to warmer temperatures. The wide geographic distribution of livestock attests to their adaptability to various climates.[24] Some simple adaptations to warmer climates include adjusting shading and air conditioning,[24] and the use of sprinklers to cool livestock during excessive summer heat,[57] although these options may incur considerable expense.

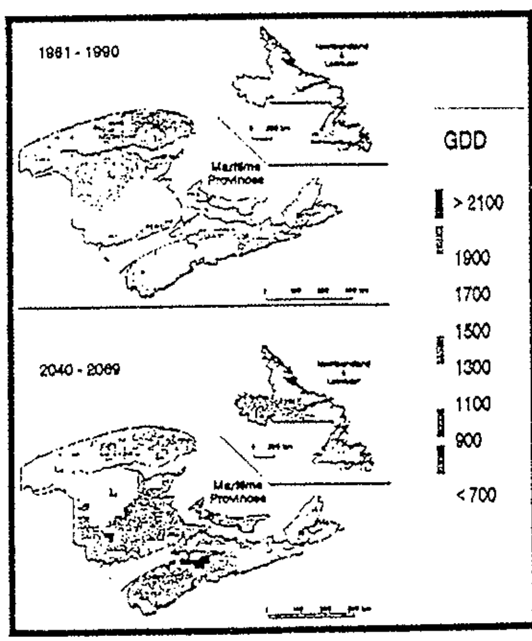
Adapting to changes in moisture availability and extreme conditions may be more challenging. For the beef industry, options that have been discussed include advancing the date when livestock is turned out to pasture, increasing intensive early season grazing, and extending the grazing season.[66] The success of these strategies is expected to vary with location and pasture type. The introduction of new breeds and/or species may also play a significant role in reducing climate change impacts on livestock.[24] It is noteworthy that none of these actions are likely to prove effective in mitigating the impacts of extreme climate events, such as the 2002 Prairie drought that has forced many ranchers to sell off cattle.

Sound land management practices are essential for soil conservation, which, together with flexibility regarding land use, will help minimize the impacts of climate change on agricultural soils.[67] Long-term management strategies that increase soil organic matter, so that soil has a high nutrient content and strong water-holding capacity, will also render the land better able to cope with future climatic changes.[68]

BOX 6: Adapting in the Atlantic Provinces [13]

Longer and warmer growing seasons are projected for the Atlantic Provinces (*see* figure below). To take advantage of these new conditions, producers are expected to adjust the types of crops grown, and introduce new hybrids. For instance, crops such as corn and soybeans are expected to increase in dominance, whereas small grain cereals will likely decrease. Producers should also be prepared to introduce new corn hybrids, which are adapted to warmer conditions, such as those currently used in southern Ontario.

However, warmer temperatures are not the only factor influencing crop decision-making. Researchers point out that small grain cereals are unlikely to be phased out completely, as they work well in rotation with potatoes and provide straw for animal bedding. Other considerations include production costs, protein levels and financial returns of different crops. The suitability of the soil, moisture conditions and the influence of crop type on soil erosion must also be considered.



Projected number of growing degree days (GDD) above 5°C (uses the Canadian CGCM1 with aerosols)

Agricultural Policies

"The ability of farmers to adapt...will depend on market and institutional signals, which may be partially influenced by climate change." (22)

Government programs and policies, such as tax credits, research support, trade controls and crop insurance regulations, significantly influence agricultural practices.[55] For example, recent reform of the Western Grain Transportation Act has contributed to increased crop diversification on the Prairies.[69] Programs and policies may act to either promote or hinder adaptation to climate change.[58] Researchers have suggested, for instance, that crop insurance may tend to decrease the propensity of farmers to adapt.[70]

It has been suggested that policies designed to promote climate change adaptation in the agricultural sector must recognize the dynamic nature of both the biophysical and social systems in agriculture.[25] There is a need for designating responsibility for action, as adaptation occurs at many levels.[55] A general goal of policy development should be to increase the flexibility of agricultural systems and halt trends that will constrain climate change adaptation.[25, 71] No-regrets measures that improve agricultural efficiency and sustainability, regardless of climate change impacts, are also encouraged.[25]

Producers' Attitudes toward Adaptation

Agricultural producers have demonstrated their ability to adapt to changes in climate and other factors in the past, and they will continue to adapt in the future. However, the key question for agriculture is whether adaptation will be predominantly planned or reactive. The answer appears to depend largely on the background, attitudes and actions of individual producers.[56]

Producer interviews and focus groups reveal that, to date, there is generally little concern in the Canadian agricultural community regarding climate change (e.g., references 57, 58, 72). These attitudes have been attributed to the confidence of producers in their ability to adapt to changing climatic conditions, and their tendency to be more concerned with political and economic factors.[58, 73] Indeed, numerous studies have demonstrated that financial and economic concerns are the primary influence on producer decision-making. This does not mean that adaptation to climate change will not occur, but rather suggests that climate change adaptations will be incidental to other adaptations, and should be viewed as one element of an overall risk management strategy.[73]

It is also possible that events such as the 2001 drought are changing producers' attitudes toward climate change, particularly when viewed as an analogue of what might be expected in the future. Multiyear droughts seriously challenge the adaptive capacity of agriculture. At workshops held across the Prairies, acceptance of climate change as an important issue has become common, as has a growing recognition of the need for action.[74]

Socio-economic Consequences of Adaptation

As other countries take action to adapt to climate change, Canada will need to keep pace or risk being placed at a competitive disadvantage.[55] In fact, successful anticipatory adaptation in the agri-food industry could provide Canadian producers with a competitive advantage. Before promoting adaptation options, however, it is necessary to consider the full range of socio-economic impacts. For example, although switching production to a new crop may increase overall agricultural production, it may not be economically viable due to marketing issues and higher capital and operating costs.[25] Since more than 98% of Canadian farms are family owned and operated,[5] the effect that adaptation options to climate change will have on culture and livelihood must also be considered.

Knowledge Gaps and Research Needs

Although understanding of the potential impacts of climate change on Canadian agriculture has improved, a number of key knowledge gaps, particularly with respect to the process of agricultural adaptation, need to be addressed in order to fully assess vulnerability. As with other sectors, emphasis has been placed predominantly on the biophysical impacts of climate change, with less attention given to socio-economic impacts. Research on climate change impacts and adaptation in the food-processing sector is also sparse. There is a need for more integrated costing studies, which consider all potential impacts of climate change on the sector, as well as adaptation options. Such information is necessary not only for domestic issues, but also to assess comparative advantages within global agricultural commodity markets. Comparisons between studies and regions will be assisted by more standardized use of climate change scenarios and crop production models. Research is also needed to determine what barriers exist to adaptation in the agriculture sector and how these can be addressed. Increased use of new methodologies for assessing vulnerability would help to address these gaps.

Another important focus for agricultural research is the identification of thresholds. The agriculture sector has proven itself to be highly adaptive, but this adaptation takes place within a certain range of climate conditions. New adaptive measures may serve to expand this range somewhat, but there exist climatic thresholds beyond which activities are not economically viable and substantive changes in practices would be required. An improved understanding of where these critical thresholds lie will contribute to the development of appropriate adaptation strategies.

Needs with respect to primary agricultural production, as identified within the recent literature cited in this report, include the following:

Impacts

1) Increased focus on the impacts of changes in the frequency of extreme events, rather than mean conditions, on both crops and livestock
2) Improved understanding of potential changes in wind regimes and their impacts on agricultural production
3) Studies on how climate change will affect the intensity and distribution of weeds, insects and diseases, and incorporation of these findings into impact assessments
4) More comprehensive studies of the impacts of climate change on specific farm types and regions in Canada
5) Analyses of the effects of climatic changes and CO_2 fertilization on pastures and grasslands
6) Improved understanding of the role of international markets in determining the economic impacts of climate change on Canada

Adaptation

1) Studies that designate responsibility for action, by determining which adaptations are appropriate for which groups (e.g. producers, industry and government)
2) Improved understanding of the physical and socio-economic consequences of different options for adaptation
3) An assessment of the effects that trade and other agreements will have on promoting climate change adaptation or maladaptation
4) Studies that address the role of adaptation in decision-making at the farm, industry and governmental levels
5) Better understanding of the mechanisms for expanding the general adaptive capacity of agriculture

Conclusions

Although warmer temperatures, longer growing seasons and elevated CO_2 concentrations are generally expected to benefit agriculture in Canada, factors such as reduced soil moisture, increased frequency of extreme climate events, soil degradation and pests have the potential to counteract, and potentially exceed these benefits. Some regions could experience net gains, while others may see net losses. Regional variations will result from several factors, including the nature of climate change, the characteristics of the farming system/organization, and the response of different groups.

Appropriate adaptations have the potential to greatly reduce the overall vulnerability of agriculture to climate change. These adaptations will require the participation of several different groups, including individual producers, government organizations, the agri-food industry and research institutions. Historically, the agricultural sector has proven itself to be highly adaptive to environmental and social changes, with a strong capacity to adapt in a responsive manner. However, to most effectively reduce vulnerability, anticipatory adaptation is necessary. For example, efforts to increase adaptive capacity through diversification and the development of new technologies represent valuable types of proactive adaptation. Anticipatory adaptation is also important with respect to major capital investments by producers and the agri-food industry.

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TABLE 9. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED BIOFUEL PRODUCTION

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Conduct full-cycle analysis of modern Canadian ethanol plants, including direct and indirect impact on GHG emissions. (24, 11)				Increased grain product costs to the consumer
Analyze the benefits of regional ethanol plants relative to reduced fuel transportation costs and related GHG emissions. (11)				Increased grain product costs to the consumer
Conduct Delphi-type discussions of future direction and strategies for biofuels. Include energy companies, commercial biofuel companies, farm organizations, renewable energy organizations, researchers, governments, consultants, etc. (24, 11)				Increased grain product costs to the consumer
Harvest biofuels from grasslands with high carbon-fixing plant species such as switch grass. (7)				

TABLE 8. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED SHELTERBELTS AND FARMYARD TREE PLANTING

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Encourage the planting of trees for farmyard, field and roadside shelterbelts. (27)	4,458,480		cost of land area taken out of production	

Apply manure on the basis of soil tests. (9, 3)				
Inject or immediately incorporate manure into the soil. Promote band application. (3)			Suited to coarse and medium textured soils only	
Time manure application to match crop needs. Avoid fall application. (5)	500,000		Very narrow window between spring thaw and seeding. Increased problems with soil compaction. Increased manure storage costs	
Alter animal diets to reduce manure Nitrogen excretion. (1, 5)				
Mitigation strategies should focus on GHG mitigation, not nutrient recycling. (12)				

Encourage a change in management practices in solid manure systems for barns that would include reduced use of organic bedding (straw and wood chips), more frequent removal of manure from the barn and maintenance of clean, dry facilities. (3)				
Encourage more intensive pasture management with less overgrazing. (7, 3)				
Housing with liquid manure handling systems should transfer manure to storage frequently, minimize bedding, separate solids from liquids, and maintain clean, dry facilities. (3)				
Manure storage facilities should be designed to increase storage capacity, reduce exposed surface area and reduce storage temperatures of manure. (3)				
Solid storage systems should have a cover (roof), an impermeable base and run-off control. (5)	440,000-1,310,000		Cost of storage cover	
Storage tanks and lagoons should be covered. (5)	560,000-5,510,000		Cost of storage cover	
Concrete pits or tanks under barns should use covers and low temperatures. (3)				
Bottom-loading tanks should be used to reduce aeration. (3)				
Develop and promote the use of acidifiers and nitrification inhibitors for liquid and semi-solid manure storage. (3)				
Encourage controlled composting. (3)				
Encourage anaerobic digestion. (3)			High capital costs	
Separate solids from liquids. (3)			High capital costs	
Build large scale central treatment facilities to service several livestock operations. (3)			High capital costs	
			High capital costs	Potential energy source

TABLE 7. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED MANURE MANAGEMENT

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Develop a computer based decision support system (i.e. MCLONE) for livestock producers that deals with manure management from the perspective of feed input, manure handling, manure storage, land application, soil incorporation and crop uptake. (12)		Limited data available		
Support research to establish CH_4, CO_2 and N_2O emission rates over the entire duration of manure storage across a wide range of manure types and under our various climatic conditions. (12, 17)		Best management practices promoted have not been assessed relative to GHG emissions		
Taking the necessary steps to ensure that the next farm survey conducted by Census Canada will yield more useful information relative to manure storage and land application for estimations of GHG emission calculations. (17)				
Investigation of GHG emissions from bedded manure packs in animal housing as this practice is being promoted as an environmentally sound manure management system. (17)		Best management practices promoted have not been assessed relative to GHG emissions		

Increase land area used as farm wetlands (including riparian zones) by 598,000 hectare over BAU baseline. (6)	1,902,400		Loss of income from land taken out of production. Infrastructure costs estimated to be $5,000/ha. Increased pest damage to crops	Wetlands may become major sources of GHG if later drained or dried due to reduced precipitation or increased temperatures (global warming)

Increase land area that has improved surface drainage by 40,000 hectare over BAU baseline. (6)	0		Estimated to cost $1,100 per hectare. Could increase yields by 20%	Potential increase in discharge of contaminants from drainage ditches
Increase land area that has subsurface drainage by 631,200- 3,713,400 ha over BAU baseline. (6)	0		Estimated to cost $1,100 per hectare. Could increase yields by 20-50%.	
Increase land area on which a controlled water table is used by 37,200-7,143,000 ha over BAU baseline. (6)	0		Estimated to cost $625 per hectare. Could increase yields by 5-15%.	Potential increase in discharge of contaminants from drainage ditches
Increase land area used for water diversion terraces and grassed waterways by 40,000-80,000 hectare over BAU baseline. (6)	14,100		Loss of income from land taken out of production. Infrastructure costs estimated to range from $5,000/ha for terracing to $10,000/ha for waterways	
Increase land area used for filter strips or sediment basins by 50,000-100,000 hectare over BAU baseline. (6)	4,890		Loss of income from land taken out of production. Infrastructure costs estimated to be $2,000 per hectare	

TABLE 6. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED WATER MANAGEMENT IN AGRICULTURE

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Increase use of irrigation in British Columbia, Alberta and Saskatchewan.[§] (6) [§]Note: Increased irrigation in Manitoba resulted in neutral or net increase in GHG emissions	62–82	Cost of infrastructure to source water is not known Net effects of irrigation on N_2O flux from land are not known	Reduced reliance on weather and increased yields but increased costs of production	Increased potential of groundwater contamination. Increased demand on surface and groundwater sources– leading to potential ownership issues and conflict with non-agriculture water users
Improved efficiency of energy and water use for irrigation systems. (6)	220	Cost/benefit ratios of alternative irrigation systems relative to net GHG emissions and farm income required	Conversion to alternative energy sources will require infrastructure costs	
Improved fertilizer use on irrigated lands. (6)				

TABLE 5. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED CARBON SEQUESTRATION THROUGH USE OF CROP RESIDUE FOR INDUSTRIAL PRODUCTS

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Use surplus straw from forage seed and wheat production for strawboard manufacture. (2)	3,544,164			Should be avoided in Brown and Gray Luvisolic soil zones due to erosion
Use flax straw in the production of industrial plastic composites. (2)	295,068	Net GHG savings not known		
Use straw for construction of straw bale houses. (2)			Alternatives to build energy efficient houses exist with other high Carbon materials	

Addition of nitrates to ruminant diets as a competitive methane inhibitor. (1)	129,000-165,000	Can be toxic, need to research optimum levels		May cause small increases in manure N output
Addition of malate to ruminant diets. (1)	71,000 - 263,000 and manure Nitrogen output by 700--2700 tonnes per year	Technology is in experimental stage		

Improve forage quality. (1)	315,000–917,000 and manure Nitrogen output by 8,900 –14,500 tonnes per year	On farm technology to rapidly estimate forage digestibility and quality		
Reducing fat content in market cattle and milk can reduce GHG emissions if a severe policy change is implemented. Otherwise major increases in emissions are expected with recent grading changes in the Canadian system. (1)	478,000 and manure Nitrogen output by 5000 tonnes per year	Low fat meat is undesirable due to palatability and tenderness issues	Reduced production costs. Potentially higher processing costs	Reduce fat content in our diets
Improved reproductive performance in cattle. (1)	407,000–762,000 and manure Nitrogen output by 4000–7400 tonnes per year	Commercial advancement of genetic and reproduction technologies		
Increasing the incidence of twinning in cattle. (1)	22,000–62,000 and manure Nitrogen output by 200–500 tonnes per year	Need to develop cattle lines that can regularly produce twins with minimal calving problems		
Use of specific methane inhibitors (i.e. bromochloromethane complexed with cyclodextrin or amichloral hydrate). (1)	7,506,000	No compounds currently registered for use Effect of inhibitors on animal performance and product quality are not known		Potential public resistance to widespread use of chemical inhibitors

Reduce dietary Nitrogen in ruminant diets. (1)	manure Nitrogen output by 14,700–22,700 tonnes per year		May increase production costs	
Increase rate of gain in weaned beef calves during the backgrounding phase. (1)	0		Match calving time and marketing time more closely	Encourages greater use of feedlot feeding with negative impacts on people living close to feedlots
Increase growth rate of weaned calves. (1)	716,000–964,000 and manure Nitrogen output by 7,200–9,700 tonnes per year		Trade issues regarding use of implants	Increased use of implants Reduced manure Phosphorous output
Increase milk production using, for example, growth hormone. (1)	22,000–44,000 and manure Nitrogen output by 2,000–4,000 tonnes per year	BST not approved for use in Canada	Improved feed efficiency	Reduced manure Phosphorous output
Improve feed efficiency in cattle using, for example, ionophores. (1)	196,000–723,000 and manure Nitrogen output by 1,900–6,900 tonnes per year	Long term potential to directly reduce CH_4 emissions has not been validated at a commercial scale	Improved feed efficiency	Reduced manure Phosphorous output

Add phytate to pig diets. (1)	6,300-12,642 and manure Nitrogen output by 14,896,000-29,793,000 tonnes per year	Research to verify the high animal response to phytase in Canadian systems.	May increase production costs	
Market boars instead of barrows. (1)	3,906–7,791 and manure Nitrogen output by 7,368,000–14,736,000 tonnes per year	Research into feeding boars required Research to minimize boar taint required	Legalize slaughter of intact male pigs required	Food quality issue related to boar taint
Reduce non-starch polysaccharide intake by 10%. (1)	13,356–26,775	Results from enzyme use are not consistent		
Reduce dietary protein by 15% for all poultry diets. (1)	reduce manure Nitrogen output by 7,55–15,105 tonnes per year		May increase production costs	
Improve feed efficiency in poultry by 15%. (1)	manure Nitrogen output by 2,514–5029 tonnes per year		May increase production costs	
Improve performance of poultry barns by 5%. (1)	manure Nitrogen output by 951–1,903 tonnes per year		Would target the least efficient operations	
Addition of â-glucanase to poultry diets. (1)	283–565 and manure Nitrogen output by 951–1903 tonnes per year			

TABLE 4. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED
LIVESTOCK FEEDING & MANAGEMENT

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Increased use of production enhancing agents to reduce GHG emissions per unit of product from dairy, beef and other ruminants. (10)				—
Improved animal management to reduce GHG emissions per unit product from all livestock production systems. • improved genetics • improved reproduction • controlling disease. (10, 15)				—
Develop database for enteric emissions from ruminant animals in Canadian production systems. (10, 13)				
Improve growth performance of pigs by 10%. (1)	6,300–12,642 and manure Nitrogen output by 16,833,000–33,666,000 tonnes per year	Genetic potential of pig is not known	May increase production costs	May compromise animal welfare

Managing depth of denitrification and nitrification processes. (9)				
Manage carbon from manure, compost, legume residue and other crop residue. (8)				

Managing application of high rates of manure Nitrogen in the spring and fall in British Columbia. (9)	1,271,000–26,350,000	Don't know current fall application patterns Introduce broad-based technical information and transfer program for targeted regions and crops Develop better quantitative estimates of N_2O reductions with change in practice		
Maintain conditions of good aeration and manage soluble carbon and water to minimize conditions of denitrification by: • shallow incorporation of manure • uniform distribution of N • management of crop residue • soil pH adjustment to reduce rate of denitrification. (8)				
Timing Nitrogen availability to match crop requirements by: • development and use of controlled release fertilizers • development and use of urease and nitrification inhibitors • increase use of split applications of fertilizer N (side dressing) • use of legumes in rotations. (9)				

TABLE 3. SUMMARY OF GHG MITIGATION TECHNOL[illegible]ES AND STRATEGIES CONSIDERED
SOIL NUTRIENT MANAGEMENT

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Determine the impact of fertilizer form and placement, legume crops, and tillage systems on N_2O emissions with particular emphasis on their interactions. (16, 14)				
Understand the controls and mechanisms of spring thaw and over-winter emission for N_2O and develop low emission strategies for various regions in Canada. (14)				
Determine the ratios of N_2O produced per unit of NH_4^+ or NO_3^- denitrified. (14)				
Quantify agricultural contributions to off-site N_2O emissions. (14)				
Partition of sources of N_2O emissions. (14)				
Determine the relationship between soil texture and annual N_2O losses. (9)				
Soil test at seeding and adopt a 20 kilogram per hectare reduction in Nitrogen application on corn in Ontario. (9)	136,400	Confirm at response curves local level	$6.00 per hectare revenue loss	

Reduce the practice of crop residue burning and encourage over-winter residue.	Low	Net effect on GHG mitigation not known	Increased field crop disease problems—suited to medium and coarse soils only	
Application of manure and sewage sludge on land as nutrient source.		Net effect on GHG mitigation not known		
Expand access to soil testing and encourage precision farming.		Should reduce N_2O emissions, but extent not known	Increased production costs	
Increase land acreage that is farmed using minimum or zero tillage.	110,000–2,468,000	Ability to measure soil Carbon gains is difficult—limited regional data relative to differences for N_2O emissions from various tillage systems`	May affect emergence and development of plants for certain crops in Eastern Canada due to cooler spring soils	A shift to increased herbicide use
Reduction of summerfallow.	188,000–662,000		Increased risk of poor yields in more arid regions—increased fertilizer and herbicide requirements	

TABLE 2. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED
SOIL MANAGEMENT OF CULTIVATED LANDS

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Development of innovative practices for deep placement of Carbon.				
Increased research to reduce risk and increase production when using reduced tillage practices.				
Develop baseline data; quantify emissions from all sources; and conduct comparisons of management scenarios in the various regions of Canada. Models need to be refined by incorporating accurate data and should be focused on both CO_2 and N_2O. Existing models include Expert-N, CENTURY model, DeNitrification DeComposition model, and ECOSYS. (16)				
Rather than devoting a high level of resources toward trying to measure soil Carbon and soil Carbon change, which will then be used to develop complicated models with a high degree of uncertainty, we should focus on criteria that serve as indicators or criteria to determine loss or gain of soil Carbon; i.e. a measure of plant biomass returning to the soil annually.				

Conversion of alfalfa land in Aspen Parkland/Boreal Transition Region to native rangeland. (7)	269			Reduced income in the target areas
Converting away from commercial Nitrogen towards manure Nitrogen sources for hay land fertilization. (7)	26,794			
Optimizing soil fertility and grazing management on tame pastures in Western Canada. (7)	38.1			
Introduction of grass legume mixtures and rotational grazing of tame pastures in the Boreal Shield, Montane Cordillera, Aspen Parkland/Boreal Transition and Peace River Lowland. (7)	32.2		Increased cost of production	
Reduced stocking rate on over-grazed tame pastures in the dry prairie regions. (7)	14.5			

Appendix D

Tables 1–9 represent mitigation technologies and strategies that were presented to the Agriculture and Agri-Food Climate Change Table for consideration in the process of developing the Options Report and its recommendations.

TABLE 1. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED AGRICULTURE GRASSLANDS

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year) using a 20-year average	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Improved grazing management on native grasslands-strategic dietary supplementation. (10)*				
Improved grazing management on native rangeland-complementary grazing. (7)	139,985,750			
Improved grazing management on native rangeland-reduced stocking rates. (7)	342,464,550		Increased production costs	
Increased rotational grazing on natural pastures of Eastern Canada. (7)	34,929,550			
Rotationally grazing tame pastures in Atlantic Maritime, Mixed Wood Plains and Pacific Maritime regions. (7)	17.7		Producers need to become better pasture managers	
Covering highly eroded crop land with permanent grass. (7)	126.6			
Increasing forages in rotation from 50% to 70%. (7)	448		Reduced annual crops and potential excess of forage	

*numbers in brackets coincide with references

Appendix C

Expert Papers presented at the Montreal meeting of the Agriculture and Agri-Food Table. Full text articles available from Agriculture and Agri-Food Canada s Environment Bureau. Abstracts are available on the world wide web at :
(http://aceis.agr.ca/policy/environment/sustainability/stewardship/climate_change/table/abstract.html)

Title	Authors
Greenhouse Gas Emissions from Agriculture and the Canadian Commitment at Kyoto	Charles Mrena
Land Use and Climate Change	Charles Mrena
Nitrous Oxide Emissions from Canadian Agroecosystems: Understanding the Process	R.L. Lemke, P. Rochette, and E. VanBochove
Developing methods to predict N_2O emissions in crop production systems	W.N. Smith, R. Lemke, R.L. Desjardins
Quantifying, predicting and verifying changes in soil carbon	B.H. Ellert
Validating Greenhouse Gas Flux Estimates from Agroecosystems	E. Pattey and R.L. Desjardins
IPCC Greenhouse Gas Accounting and Agriculture	Marie Boehm and Ira Altman
The Economics Of Reduced Tillage And Reduced Summer Fallow In Crop Production In Canada: A Review Of Available Evidence	Michael Rossetti and Glenn Fox
Economics of Biofuels	Ewen Coxworth and Andre Hucq
Greenhouse Gas Emissions From Manure and Measures For Their Mitigation	Daniel I. Massé and Francis Croteau
Potential For Reducing GHG Emissions From Domestic Monogastric Animals	Candido Pomar
Rangeland Cattle Production And The Greenhouse Effect, A Review	J.C. Kopp and K.M. Wittenberg
Ruminant Livestock Methane Emissions: Potential for Mitigation	D. Boadi and K.M. Wittenberg
Livestock Manure Management Systems and Greenhouse Gases Production	Sylvio Tessier and Alfred Marquis
The Economics Of Modified Manure Handling Systems For Greenhouse Gas Reductions	Gregory De Vos, Alfons Weersink, Peter Stonehouse
The Economic Feasibility of Modified Feed and Rumen Management to Reduce GHG Emissions	Scott R. Jeffrey
Adapting to Climate Change in Canadian Agriculture	Allen Tyrchniewicz
How Will Greenhouse Gas Policy Affect The Competitiveness Of Canadian Agriculture	Allen Tyrchniewicz
Complimentarities And Conflicts In Policies Relating To GHG Emissions And Agriculture	Edward Tyrchniewicz
Clean Development Mechanisms And Agriculture	Edward Tyrchniewicz
Non-Market Policy Instrument Options For Reduced GHG Emissions From Agriculture	Don Buckingham and Cynthia Kallio Edwards
Incentives For Early Action And Timing Of Greenhouse Gas Policies For Agriculture	Richard Gray and Dan Monchuk
Market Instruments Options For Reduced GHG Emissions from Agriculture	Allen Tyrchniewicz

June 9-11, 1999	Truro, NS	• Presentation of remaining Phase I studies • Selection of options to go forward to Stage II of Phase I.
July 22 & 23, 1999	Ottawa, ON	• Presentation on Phase II analysis. • Consideration of Phase II analysis
Aug. 26 & 27, 1999	Ottawa, ON	• Development of Options Paper • Consideration of Phase II analysis
October 15, 1999	Ottawa, ON	• Development of Options Paper • Presentation of Options Paper
November 15, 1999	Toronto, ON	• Evaluation of Actions and Measures • Discussion of Options Paper
November 30, 1999	Conference call	• Final approval of Options Paper

Appendix B

Meeting dates and locations for the Agriculture and Agri-Food Table.

Date	Event Location	Outcome(s)
June 30, 1998	Table Pre-Meeting, Toronto, ON	
September 9, 1998	Winnipeg-Ottawa (Video conference)	• Identification of areas for further study • Discussion of Early Action items
October 23, 1998	Winnipeg, MB	• First review of the Foundation Paper • Update on Early Action proposal, • Presentation by PAMI
November 19 & 20, 1998	Montreal, QC	• Presentation and discussion of commissioned papers • Collaboration with Forestry Table initiated
December 14 & 15, 1998	Calgary, AB	• Prioritization of measures for Phase I analysis • Identification of Phase I contract teams • Decision to contract Food Processing Foundation Paper • Presentation by PFRA, Alberta Food Processing Industry, Canadian Fertilizer Institute, Public Outreach & Education, Modeling and Analysis Group
January 27, 1999	Hull, QC	• Presentation on GHG Emissions Inventory, Emission Trading • BIOCAP Presentation • Discussion of Phase II modeling
February 19, 1999	(Conference call)	RFPs for Phase I Studies Issued Sub-committee established for Options Paper
April 6 & 7, 1999	Winnipeg, MB	• Final review of Foundation Paper • Report Enhanced Voluntary Action Table, Sinks Table • Contractors for Phase I studies announced
May 6 & 7, 1999	Ottawa, ON	• Presentation on Emissions Trading • Phase I Reports – Nutrient Management, Soil Management & Manure Management • Sinks Table Sub-committee Report • Presentation Adaptation in Agriculture

Appendix A

Agriculture and Agri-Food Table Membership.

Member	Organization
Co-chairs	
Les Haley	Agriculture and Agri-Food Canada
Garth Sundeen	Canadian Federation of Agriculture
Members	
André Bédard/ Jean-Paul Lussia-Berdou	Québec Ministère de l'Agriculture, des Pêcheries et de l'Alimentation
Jean Brodeur	Cooperative Fédérée du Québec
Jim Bruce	Soil and Water Conservation Society
David Burton	Canadian Society of Soil Science
Jean Louis Daigle/ Gordon Fairchild	Eastern Canada Soil and Water Conservation Centre
Peter Dzikowski	Alberta Agriculture, Food and Rural Development
Jim Farrell/ John Harapiak	Canadian Fertilizer Institute
Sheila Forsyth	National Agriculture Environment Committee
Alexandre Lefebvre/ Eric Aubin	Canadian Pork Council
Richard Gray	University of Saskatchewan
Suren Kulshreshtha	Agriculture and Agri-Food Canada
Daniel Masse	Agriculture and Agri-Food Canada
Douglas Mutch	Canada Grains Council
Katharine Schmidt/ Susan Antler	Food and Consumer Products Manufacturers of Canada
Paul Smith	New Brunswick Department of Agriculture and Rural Development
Peggy Strankman	Canadian Cattlemen's Association
Ed Tyrchniewicz	International Institute for Sustainable Development
Karin Wittenberg	University of Manitoba
Nigel Wood	Ontario Ministry of Agriculture, Food and Rural Affairs
Brian Yusishen	Manitoba Agriculture
National Climate Change Secretariat	

Forthcoming:

Junkins, B., S. Kulshreshtha, P. Thomassin, A. Weersink, K. Parton, R. Desjardins, M. Boehm, R. Gill, C. Dauncey. "Analysis of strategies for reducing greenhouse gas emissions from Canadian agriculture." Technical report to the Agriculture and Agri-Food Table. Policy Branch, Ottawa: AAFC, 2000.