Agriculture and Climate Change
A Prairie Perspective

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TABLE OF CONTENTS

Introduction 3

Prairie Agriculture: The Biophysical and Socio-Economic Context 4

Climate and Agriculture: The Prairie History 6

Prairie Agriculture: Climate Change Impacts 8
- Agroclimatic Conditions 8
- Crop Yields 8
- Livestock Production 10
- Economic Impacts 10
- Agriculture Policy 11

Issues for Future Impacts and Adaptation 11
- Competitive Advantage in Global Market 14
- Socio-Economic Conditions and Agriculture Policy 15
- Agriculture and Sustainability 17

Recommendations 18

References 19

Introduction

Agriculture is an economic activity that is highly dependent upon weather and climate in order to produce the food and fibre necessary to sustain human life. Not surprisingly, agriculture is deemed to be an economic activity that is expected to be vulnerable to climate variability and change. The vulnerability of agriculture to climate variability and change is an issue of major importance to the international scientific community, and this concern is reflected in Article 2 of the UNFCCC, which calls for the:

> ...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent serious anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to: (i) allow ecosystems to adapt naturally to climate change; (ii) ensure that food production is not threatened; and (iii) enable economic development to proceed in a sustainable manner.

On a global basis, climate variability and change may have an overall negligible effect on total food production (Parry and Rosenwieg, 1994); however, the regional impacts are likely to be substantial and variable, with some regions benefiting from an altered climate and other regions adversely affected. Generally, food production is likely to decline in most critical regions (e.g. subtropical and tropical areas), whereas agriculture in developed countries may actually benefit where technology is more available and if appropriate adaptive adjustments are employed.

In terms of undertaking a national assessment of climate change impacts on Canadian agriculture, this sector has received considerable attention relative to other resource sectors. There has been a significant amount of research and studies directed at climate change and agriculture in Canada, and much of this literature has already been compiled in annotated bibliographic form (e.g. Wheaton, 1994). Further, agriculture has received attention on a regional basis (e.g. the MBIS, the GLSLB Project, and the proposed Prairie Climate Impact and Adaptation Study), and some areas, such as parts of the Prairies, have been examined in terms of its palaeo record (the Palliser Triangle Study), and current and future climate (the Nat Christie Foundation Project in Alberta). Although there is a substantive body of literature focusing upon climate change and agriculture, there continues to be a wide range of opinions regarding scenarios of future impacts. In the Prairies, for example, which is an agricultural area of significant global, national and regional importance, the most recent IPCC Assessment Report presented a guardedly optimistic, and yet foreboding appraisal:

Increased agricultural production on the Prairies is a possibility with higher temperatures and CO_2 levels, provided adaptation measures are undertaken and adequate rainfall occurs. However, some models project more frequent and serious drought (Canadian Climate Program Board, 1995, p. 5).

Notwithstanding this appraisal, it is undeniable that Prairie agriculture has had an explicit history in terms of its vulnerability to the vagaries of climate. The drought of the 1930s, and most recently in 1988, illustrates the sensitivity of agriculture in this region to severe moisture deficits. Combined with recent floods, the ever presence of hail damage, and other climatic events (e.g. early autumn frost), the historical record and current conditions underscores the variability of climate and the negative effects from extreme weather events.

Given the historical sensitivity of Prairie agriculture to climate, the uncertainty which exists in our scenarios, and the economic and social importance of this sector, there is a strong need to improve our understanding of climate change impacts and the adaptability of Prairie agriculture. As a first step to address this need, the purpose of this paper is to present a brief overview of the literature on agriculture and climate change impacts and adaptation in the Prairies.

The paper is organized into 5 sections and begins with a brief description of agriculture in the prairies, establishing the biophysical and socio-economic context. The next section presents an historical synopsis of agriculture and climate, highlighting the adverse impacts associated with extreme moisture deficits, or droughts. In section IV, the discussion focuses upon climate change impacts, and is organized following the research protocol: (i) agroclimatic conditions; (ii) crop yields; (iii) livestock production; (iv) economic impacts; and (v) agriculture policy. Issues influencing future impacts and adaptations are discussed in section V, specifically changes in socio-economic conditions and agricultural policy, exports and comparative advantage, and sustainable development. In the conclusions, knowledge gaps are identified and a list of recommendations and questions for further research is presented.

Prairie Agriculture: The Biophysical and Socio-Economic Context

Prairie agriculture is located in a physiographic region known as the Western Interior Basin (Plains) and includes the northern portion of the Great Plains ecozone. The natural vegetation of this region is primarily grassland, extending southward from the Boreal Forest into a transition zone of Aspen Grove to Mixed-grass Prairie and Short-grass Prairie, with the northern tip of the True Prairie grassland extending into south eastern Manitoba. The soils of the interior plains are quite fertile, made up of Brown Chernozemic, Dark Brown Chernozemic and Black Chernozemic soils (Watts, 1967). In terms of climate, the agricultural regions experience relatively long winters, short summers and low precipitation. Clear skies and warm temperatures generate favourable growing degree days, ranging from 1700 - 1800 in Manitoba, with Saskatchewan and Alberta receiving on average 100 - 300 less. Although precipitation tends to be relatively low, fortunately for agriculture most of the precipitation falls during the growing season, and typically during the month of June when crops can best use the moisture. Annual precipitation ranges from 400 mm - 600 mm for Manitoba, whereas Saskatchewan (300 mm - 500 mm) and Alberta (300 mm - 500 mm) tend to receive slightly less amounts of rainfall. Moisture deficits, however, tend to exist in most agricultural regions, ranging between 150 - 250 mm, and are particularly high in an area known as Palliser's Triangle. Swift Current, for example, typically experiences a moisture deficit of approximately 400 mm. Extreme weather events such as drought, tornadoes, flooding and hail tends to be a common occurrence throughout the Prairies, although the frequency and severity of these events tends to be regionally variable. For instance, the corridor between Red Deer and Calgary is known as 'hailstorm alley', experiencing some of the most numerous and severe hailstorms in the world (Phillips, 1990).

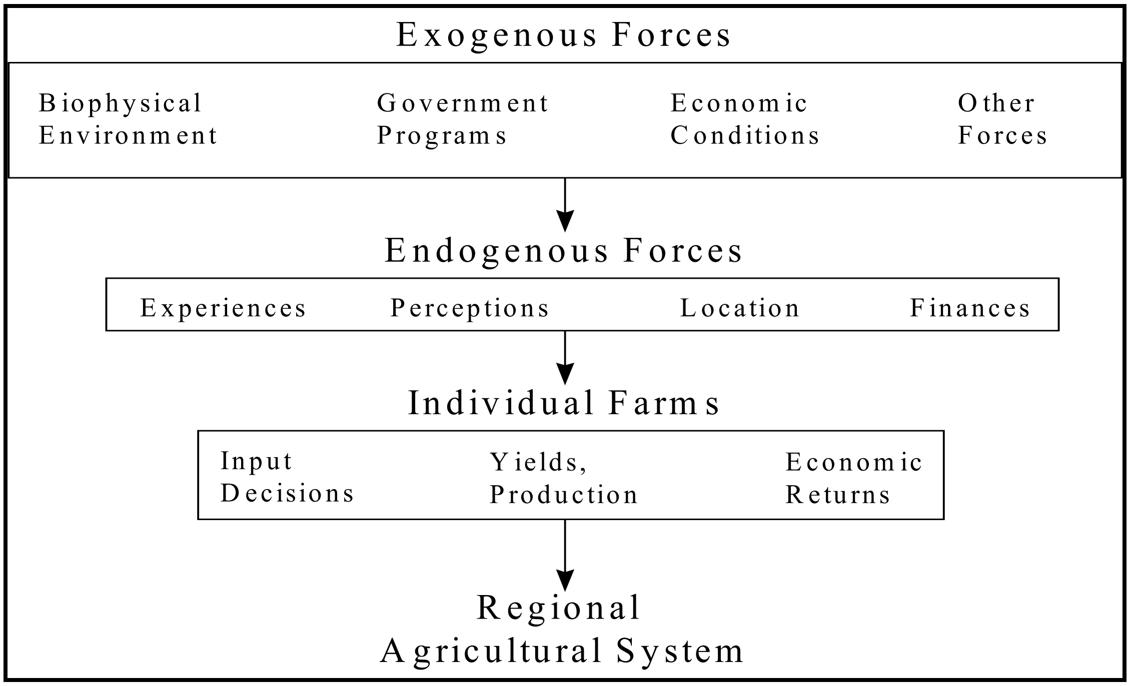
Due to this combination of rich soils and favourable agro-climatic conditions, most of the area where agriculture is now practiced are on soils classified according to the Canada Land Inventory as Classes 1, 2 and 3. Generally, these soils have few limitations to crop production, or where moderately severe limitations exist (Class 3), they can be overcome with good management practices (Statistics Canada, 1984). In the Peace River district, where soils have more severe limitations and agro-climatic conditions are less favourable, hay and pasture dominate agricultural activity. Generally, the location of agriculture, and particularly crop production, is closely correlated with soil suitability, reflecting the importance of soil and climate in determining where and what crops are grown.

Although grain production has historically been associated with Prairie agriculture and continues to account for the majority of production, in recent years many farmers have begun to diversify into specialty crops (e.g. mustard seed, dry peas and lentils). In some areas of extreme moisture deficits, extensive irrigation systems have also been developed. For example, almost 500,000 ha of farmland is currently under irrigation in southern Alberta, producing a wide variety of crops including grains, pulse crops, corn, sugar beets and vegetables. The raising of livestock is also an important agricultural activity, particularly in terms of cattle. More than 50% of Canada's beef cattle are now raised in western Canada, and much of this is concentrated in Alberta. Hog production is becoming increasingly important in the Prairies, while under supply management regulations, the region also produces most of its requirements for poultry, eggs and dairy (fluid milk) products. Livestock operations across the prairies are also diversifying with the introduction of buffalo, emus, and elk. Some farmers have recognized that the indigenous species, such as the buffalo and elk are more accustom to the climate of the prairies, than traditional livestock, and might reduce some of the climate stress.

Farming is an activity that is influenced by many exogenous and endogenous forces (Figure 1). Exogenous forces, those beyond the control of the farmers, have a major influence on the prairie farms. These forces include such things as the biophysical environment, government policy, and economic conditions. The endogenous forces are those that farmer has some control over. They include: the farmer’s experience, perceptions, location of the farm, and finance. Combining these forces results in a vast array of individual farm decisions, and when the results of each farm are combined, leads to the regional agricultural system. The agricultural system is also part of a broader agri-food system, whereby modern commercial agriculture is one stage in a food production process linking farmers and consumers via a system of processors, distributors and retailers. The agri-food system is both complex and differentiated across the Prairies, with some regions more dependent upon grains and other regions more diversified into livestock production and/or value added processing.

Canadian agri-food exports are an important source of food and fibre for the global market, and make a significant contribution to the nation's wealth and balance of payments. In 1994, the value of Canadian agri-food exports exceeded $15 Billion, with Western Canada contributing over $9.5 Billion, predominantly in wheat, barley and oilseed crops (AAFRD, 1995). According the most recent available census statistics (Statistics Canada, 1992), there were 143,791 census farms operating in the Prairies which accounted for almost $13 Billion in total farm cash receipts and over $55 Billion in farm capital investments. Provincially, agriculture and agri-food industries represent a significant proportion of the Gross Domestic Product, ranging from 5.0 percent in Alberta and Manitoba to 8.0 percent in Saskatchewan. In some regions, such as southern Alberta, the agri-food sector is the most dominant economic activity.

Figure 1. Farming forces.



Source: Smit et al. 1996

Climate and Agriculture: The Prairie History

While there are many aspects of climate to which Prairie agriculture is vulnerable, drought can inflict the most extensive damage. Drought is defined as a long period of abnormally low rainfall, especially one that adversely affects growing or living conditions (Allaby, 1989). During this century the Canadian Prairies have experienced two periods of higher than normal temperature and abnormally low rainfall/precipitation: the 1930's and the drought of 1988. In view of expectations that droughts in a future of climate change will be worse than the drought in the 1930s (Rosenzweig and Hillel, 1993; and Karl and Koscielny, 1982), it seems expedient to review the effects that these droughts had on Prairie agriculture.

The southern Great Plains were the hardest hit by the 1930's drought. It has been estimated that between 1933-1937, rainfall was only 60% of normal, devastating livestock and crop production (Phillips, 1990). Wheat yields fell 32% below normal and corn yields dropped as much as 50%. Low crop yields year after year led to the failure of about 200,000 farms and the migration of an estimated 300,000 people from the region. These disasters were a consequence of land-management practices that were associated with European techniques which came with the settlers. The practices included such things as single-wheat farming, dustmulching, mechanization, and cultivating fallow land which exacerbated wind erosion and contributed to the dust storms that extended several kilometres into the air and carried many million tonnes of dust up to several thousands kilometres away (Lockeretz, 1978). Only after the out-migration had occurred and the climate had returned to more normal levels of precipitation, did management practices such as the adoption of conservation tillage techniques and risk management programs come into effect (Rosenzweig and Hillel, 1993).

Fifty years after the "dirty thirty's" another period of severe drought occurred. The drought in 1986-1988 was more severe since the temperature was higher, as well as the precipitation deficit. Evaporation loss was also larger due to higher temperatures. As characterized by Arthur and Chorney (1992), the drought period in the 1980's was significant by its intensity, duration, area and effects. The warm and dry fall weather persisted into the winter of 1987-1988. In Alberta and Saskatchewan less than 50% of normal precipitation fell during the growing season. The mean temperature was 2-4°C above normal in March, April and May. The summer in 1988 was hot, dry and dusty, with mean temperatures 4-7°C above normal, and became the hottest summer on record for many localities. The combination of heat and insufficient moisture caused severe droughts in southern Manitoba, south central Saskatchewan and south eastern Alberta.

The effects on crop production and livestock were substantial across the Prairies, although Alberta faired relatively better than Saskatchewan and Manitoba (Arthur and Chorney, 1992). Production of the seven major grains was 29% less than in the previous year, and production of western Canada's four major specialty crops was down by 40%. Inventories were reduced significantly, and while marketing volumes were relatively high due to favorable prices and the depletion of older stock, export losses were estimated at $4 Billion (Phillips, 1990). One of the primary causes of the adverse effects was weeds, which became more problematic. The heat caused rapid growth and poor herbicide performance. The seeds were affected by poor germination and growing conditions (Arthur and Chorney, 1992). Despite the adverse effects on germination the crop quality actually increased in 1988, with dry conditions during the growing and harvest seasons resulting in a higher than average crop quality. The indirect effects through insects and diseases also changed. It has been found that the frequency and severity of strip rust epidemics on winter wheat in the pacific northwest varies in direct relationship to climatic variation (Wheaton and Wittrock, 1992).

Livestock production was also adversely affected through the effects on feed, from dust storms, and the lack of suitable pasture land due to drought or Prairie grass fires. In order to maintain their herds, cattle ranchers were forced to move their herds to more fertile areas where feed and pasture were more plentiful. In Manitoba cattle breeders moved their herds to northern areas, whereas in the US the drought pushed the herds south. The effects on cattle producers and grain farmers were helped out by a number of support programs. A combination of crop insurance and special drought assistance, for example, paid out over $1.3 billion to Prairie farmers, an amount also supplemented by Provincial support programs. Despite this support, Manitoba showed net farm income losses of 50% and Saskatchewan 78% (Arthur and Chorney, 1992). Due to the effects of the drought, and previous years of low prices, an estimated 10% of farmers and farm workers left agriculture in 1988 (Phillips, 1990).

The adverse effects inflicted by these two droughts clearly illustrate the vulnerability of agriculture to severe climate conditions. In the 1930s, land management techniques exacerbated the effects of drought, and while farming methods had improved significantly by the 1980s, the effects from the latest drought were still substantial. Combined with estimates that future droughts under climate change could be both more frequent and severe than in previous years, the vulnerability of agriculture and its capacity to adapt demands closer examination. It may be necessary for agriculture to adopt additional measures to avoid (or at least minimise) the effects from future droughts.

Prairie Agriculture: Climate Change Impacts

To assess the impact of climate change and variability on agriculture on the prairies requires some knowledge of the possible future state of the climate. General circulation models (GCMs) are the primary source of climate change scenarios which make projections about the degree and timing of climate change. GCMs are mathematical representations of the physical laws of conservation, mass, moisture and energy to create a detailed three dimensional model of the climate system. Scenarios are built based on various assumptions of greenhouse gas concentrations, the most widely used being that of a doubling of the concentration of atmospheric carbon dioxide. Depending on the mathematical and physical formulations and the starting assumptions, the resulting scenarios will vary. The three most commonly used scenarios resulting from GCMs are Environment Canada's second generation CCC GCMII, Princeton University's Geophysical Fluid Dynamics Laboratory (GFDL) GCM, and NASA's Goddard Institute for Space Studies (GISS) GCM (Taylor, 1996).

Agroclimatic Conditions

The scenarios for the prairie region all show an increase in temperature and reductions in soil moisture with a doubling of atmospheric carbon dioxide. Some models have shown an increase in precipitation while others have decreased precipitation. In either case high rates of evaporation over a longer period of time due to increases in temperature are predicted to result in diminished soil moisture. The predicted increase in temperature increases may lengthen the growing season for the prairies. An example of this is the potential reduction in the time required for spring wheat to mature by 11 days to 5 weeks depending on the location and scenario used (Brklacich, et. al., 1994). Potentially, this leads to earlier planting and earlier harvesting (McGinn et al, 1994). Opportunities for crops requiring more heating days, such as corn and sorghum, would exist for farmers on the prairies. Not only is there a potential more heating days, there is a possibility of increase in crop production in northern regions as a result of more favourable agroclimate conditions; however production is limited by soil capability.

During a typical summer, the prairies lose more water through evaporation than falls as rain making the region extremely dependent on the increased winter snowfall predicted in some models to replenish losses. Droughts could become more frequent and severe as a result. The loss of soil organic matter compounded by drier conditions will also lead to an increase in dust storms (Jones, 1996; Fosse & Changnon, 1993; & Cohen et al., 1992).

Precipitation could be the limiting factor for agriculture production on the prairies based on the current models. Not all parts of the prairies will experience the same effects, precipitation may increase in the eastern prairie and decrease in the west (Brklacich, et al, 1994). Williams, (1988), suggests that there is potential for a thirteen fold increase in the frequency of drought. With this increase in drought potential, there will be an increased demand for irrigation (Wheaton, 1994).

Crop Yields

Agriculture has always been dependent on the variability of the climate for the growing season and the state of the land at the start of the growing season. The key for adaptation for crop production to climate change is the predictability of the conditions. What is required is an understanding of the effect on the changing climate on land, water and temperature.

Research on crop yields has received significant attention on a variety of scientific fronts. Plant and soil science research has provided an indication of the potential of the Canadian prairies to produce food and fibre with given conditions. In reality, it is difficult to accurately predict crop yields, because of the variability of conditions and subsequently production on the prairies. An example of this is CO_2 enrichment. Laboratory experiments have concluded the CO_2 enrichment may benefit C3 crops (e.g. rice, wheat, soybeans, potatoes and vegetables), although these improvements found in laboratory experiments may not be realised in the field.

A temperature rise extends the growing season and the farmable area, it causes earlier maturity of grain and opens up for the growing/farming of new crops. While the temperature rise is beneficial to the crops, the extra heat also affects weeds. Weeds, pests, and insects tend to get better living conditions under higher temperatures. To further increase the risks of a good crop, there is also the potential for poor herbicide performance. The combination of the weeds, pests and poor herbicide performance reduces the potential crop yields. The increase in temperature also increases evaportranspiration, which has a negative impact on crop yields.

During the growth cycle of the plant, water is needed at the initial stages of production, but not during the final stages. Low levels of precipitation have a negative effect on the germination of the seeds. Dry conditions, frequency and severity of dust storms all result in decreased production of major grains.

Given the potential changes in production variables, it is estimated that the average potential yields may fall by 10-30% (Williams et al., 1988). Across the prairies, crops yields will vary. All crops in Manitoba may decrease by 1%, Alberta wheat, barley and canola may decrease by 7% and Saskatchewan wheat, barley and canola may increase by 2-8% (Arthur, 1988).

Table 1 outlines some of the changes expected in crop yields across the Canadian prairies.

Table 1. Changes in Crop Yields by Selected Scenarios.

Provinces	GFDL	GFDL2	GISS	GISS2
Manitoba	increase all crops	increase all crops	decrease all crops except wheat	increase all crops
Saskatchewan	increase wheat	increase all crops	decrease all crops except wheat	increase wheat
Alberta	insignificant changes	decrease all crops except barley	insignificant changes	increase all crops

Source: Arthur, 1988.

Livestock Production

The main effects of climate change on livestock from increased temperature and decreased precipitation is distress, but because livestock do not have the same limitations as crops there are potential benefits to expanding acreage.

The increasing temperatures can have varying effects, depending on when they occur. Warmer conditions in the summer can lead to stress on range and housed livestock since dry pastures, poor hay and feed production and shortages of water all lead to worse conditions for cattle. On the other hand, increased temperatures during the winter months can reduce the cold stress experienced by livestock remaining outside, as well as reduce the energy requirements to heat the facilities of those animals inside.

In the previous section, it was mentioned that crops required class 3 or better land to produce acceptable yields, however, to produce acceptable pastures does not have the same restrictions. The increased temperature would have a positive effect on the growth of the pasture, and provide better feed for livestock. This assumes that the pastures are in areas where moisture is not a critical issue.

Water resources are critical to a successful livestock operation. All livestock operations require good quality drinking water, and without it livestock will not survive. As with crops, diseases and insects could have an adverse effect on much of the livestock industry. Insects and diseases that livestock is unaccustomed to could move into the production area. Secondary effects such as dust storms and wind erosion also factor into the worsening conditions for livestock.

Livestock is more resistant to climate change than crops because of its mobility and access to feed. Livestock production could be one of the key methods for farmers to adapt to climate change through diversification of their farming mix.

Economic Impacts

Agriculture is one of the oldest economic activities. This is because it is the backbone of our food supply and without it the world’s population would experience food insecurity. For this reason any effect that climate change has on agriculture will be passed on to society and the economy too. Since agriculture is also dependent on the natural resource base, changing climate will require the adaptation of agricultural practices that accommodate the new climate while conserving the natural resource base.

It is difficult to predict the economic effects of climate change on the prairies. Grain sales in Manitoba could either rise or fall by several million dollars. If drought conditions similar to those in 1961 prevail, provincial agricultural output could decline by almost 20 percent, resulting in a loss of $400 million in revenue. Farm income in Saskatchewan could fall by $160-273 million, leading to declines of between $146 million and $248 million in provincial income. The value of agricultural production in Alberta could fall by 5 percent.

Diversification in the farming mixes can be a technique to reduce the losses. The changes in crop mixes and the other activities could lead to a new variety of exports. Other parts of the economy, such as agribusiness, transportation and wholesale and retail trade could increase in value and result in new jobs.

Agriculture Policy

Government policies have had a significant impact on current agriculture and will continue to do so (Tyrchniewicz and Wilson, 1994). Previous agriculture policies, such as the Western Grain Transportation Act and the Canadian Wheat Board Act, rewarded expansion of cropland and made land-use changes difficult (Baydack et. al., 1996). Many policies of the past have not considered the need for adaptation, because it was not viewed as an issue.

Some of the current income protection policies such as crop insurance, and the Gross Revenue Income Program, need to be reviewed with adaptation as a guiding force. Many of these programs and policies encourage certain farming techniques and products and can have a major effect on adaptation. For example, if farmers have a guaranteed income when they use a certain practice (which may or may not be sustainable) then they will be encouraged not to use another practice which could be sustainable since it is not insurable and thus does not have a guaranteed income. As a result, many farmers make products that are insurable, using techniques that are insurable despite the sustainability, or in this case, climate change implications.

The current shifts in agriculture policy are starting to allow more flexibility in production, not only in techniques, but also in products. Agriculture and Agri-food Canada has introduced a program called the Canadian Adaptation and Rural Development Fund. The focus of this program has been to assist rural communities and farmers in adapting to changes in economic policies. While the program is not aimed at climate change, there is potential to use it to have agriculture adapt to more than just economic policies. At the moment, however, the issue of climate change is viewed only from the mitigation perspective, in terms of agriculture's capacity to reduce greenhouse gas emissions and act as a carbon sink. The issue of impacts and adaptation is grossly neglected within the debate involving climate change and sustainable agriculture (Agriculture and Agri-food Canada, 1996). Unless there is a substantial shift in the thinking of Agriculture and Agri-food Canada regarding climate change and agriculture, the economic policies designed to help facilitate adaptation to changing global economic conditions may turn out to be a missed opportunity.

Agriculture is also highly dependent on water resources. Current climate change predictions indicate that new competition for water can be expected. As well, many of the current water users will have increased demands. Given the increasing pressures on water resources, many of the irrigation and water use policies will need to be reviewed as well.

Issues for Future Impacts and Adaptation

Adverse effects from climate change can be reduced through successful adaptation, which would likely be less than the cost of the impacts that would otherwise occur without adaptations. Further, we can anticipate that there could be significant implications arising from climate change for agriculture in Canada, both directly upon our own food production, and indirectly from the impacts upon competing agricultural regions in other countries. One prediction is that there could be benefits associated with climate change, with a potential increase in agricultural production as favourable agro-climatic conditions expand northward in the Prairies. Such an expansion however would be tempered by the capacity of northern soils to sustain commercial agriculture.

Canada exports 80% of its wheat on an annual basis. Barley is Canada's second largest export crop while oats and other small grain exports are confined to about 7% of production. Equal amount of grain corn are exported and imported to Canada across the US border and soybeans are brought in from the States. If the mix of crops changes (as is expected) because of an altered climate, the prairies' agricultural exports are tantamount to change too. Canada will also have to import crops that formerly were produced here. This same scenario will be true for all countries. Some may become surplus producers while others will have to import more than before and others will import and export different products than before (Smit, 1989).

Table 2. Impacts of climate change on agriculture.

Agriculture Characteristics	**Possible Impacts**	**Confidence**
Agroclimatic conditions	• decreased precipitation in an already spring/summer moisture deficit region • increased need for irrigation with reduced water availability • overwintering of insects and diseases which have previously been killed due to harsh climate • introduction of new insects and diseases with a warmer climate • some insecticides become less effective as temperature rises	medium
Crop yields	• yield loss in some areas • yield gain in other areas with good soil moisture • increased variability in world production due to changing climate leading to increased variability in prices and income • increased production of crops currently grown in small quantities such as winter wheat, sunflowers and corn	medium
Livestock production	• reduced winter cold stress on livestock • increased heat stress in summer • increased adequate feed supplies • increased reliance on good quality water	medium
Economic impact	• increased diversification of production • reduced economic activity due to less output and reduced crop income • other sectors could increase because of diversification • effect of fewer purchased inputs by the agricultural sector on the economy of the province	medium
Agriculture policy	• refer to Table 3	

Source: based on modified Wittrock et al., 1992

Competitive Advantage in Global Market

A study on Canada's comparative advantage in agriculture by Smit (1989) isolates the effect of climate change from all other environmental and socio-economic conditions that could influence Canada's competitive position. How climate change could affect Canada's relative competitive advantage with its exporting competitors, as well as influencing global food imports, should also be incorporated into future research. Smit found that opportunities for producing corn and wheat would increase based on the assumption that the United States corn and wheat belts would shift into Canada given a climate warming. Opportunities for wheat and corn production would be enhanced for Russia too while they would be diminished for most other regions in the world. Climate warming would in all likelihood also lead to less favourable conditions for the production of barley, oats and soybeans. Rice production in Asia stands to gain from a warmer climate.

While information on the effects of climate change on the major crops in the world is only available for some regions, some conjecture has been made as to how they will impact upon trade. Canada can expect exports in wheat and corn to increase. Less favourable conditions for wheat production in the rest of the world except Russia mean that other potential markets exist for Canadian agriculture. This is of particular benefit to the prairies which produce the majority of Canadian wheat. The same can be said of grain corn which potentially could be exported to the US. Trade flows in grain corn may also shift from north-south to east-west with Ontario becoming a major supplier of grain corn for the prairie livestock industry. Conclusions regarding changes in Canada's competitive position in the production and trade of other crops including barley, oats, soybeans and rice remain uncertain (Smit, 1989).

Regional differences in production mix can be expected to have an effect on the prairie economies too. Arthur (1988) conducted a study of changing cropping patterns and their economic impact for Alberta, Saskatchewan and Manitoba. Using two GCMs[1] and the assumption that CO_2 concentration in the atmosphere doubles, it was concluded that the economic impacts of changing crop mixes would be limited. Crop revenues were predicted to change by between 1 and 7 percent with most results pointing toward revenue increases. Manitoba is expected to experience the least stress as a result of climate change and moisture stress with Alberta experiencing the most, although these effects could be mitigated by altering the cropping mix. It was found that if precipitation were to decrease Saskatchewan would suffer the greatest economic loss in terms of crop revenues. Later studies by Mooney and Arthur and Arthur and Van Kooten (in Van Kooten, 1992) have concluded that Manitoba can expect a 190% increase in exports as a result of climate change if soils in the north are cultivated and higher-valued crops are substituted for those being grown now[2]. In their worst case scenarios a net revenue decline was estimated at 3%.

[1] The two general circulation models used were the Geophysical Fluid Dynamics Laboratory (GFDL) and the Goddard Institute for Space Studies (GISS) models. Trigonometric distributions were also used with these models to reflect historic daily distributions of monthly mean temperatures and the scenarios were labelled as GFDL2 and GISS2.

[2] Growing conditions, soil types and the greater availability of water in Manitoba means that a wide array of cropping options exist for Manitoba that are not available to the other two prairie provinces (Arthur, 1988). Also, arable land in northern Manitoba under warmer conditions will amount to about 4.5 million hectares, whereas Saskatchewan and Alberta can expect additional land in the north to increase by 0.4 million and 1.1 million hectares respectively (Van Kooten, 1992).

Socio-Economic Conditions and Agriculture Policy

The degree to which other sectors in the prairie economies will be affected by changes in agriculture is also determined by the share of agriculture in each province's economy. In Alberta and Manitoba, for example, agriculture only comprises 5% of total provincial GDP and so the net effect on the total provincial economy is expected to be small (Goos, 1989). Based on the above projection that Manitoba stands to benefit from the effects of climate change on agriculture, Mooney and Arthur (1990) suggest that agribusiness, transportation and wholesale and retail trade will all increase in value and result in the addition of 17,820 new jobs to the economy. It is estimated that Saskatchewan's economy will suffer considerable loss (which has not been quantified) due to the effects of climate change on agriculture in the province (Van Kooten, 1992).

Smit (1993), for example, notes that crop insurance may distort agricultural responses to climate. Similarly, the role of the marketplace in influencing farm-level decision making may become particularly important, as agricultural policy and trade becomes increasingly deregulated.

Policy adaptations could include reforming subsidies to reflect actual risk from climate; crop assistance programs could be linked to soil conservation; rural education systems could be strengthened to encourage sustainable land use practices; taxing water by volume for irrigation purposes or encouraging water conservation laws (Chiotti, ND).

Another policy consideration that will have to be taken into account as agriculture adjusts to increased climate variability and the prospect of global warming is that of food security in the rest of the world. Canada and the United States possess roughly one-sixth of the Earth's arable land and only one-twentieth of its population. For this reason Canada and the US should not have to worry about food security at home. However, if world food surpluses diminish, Canada will be faced with increasing demand for food aid as well as the ethical question of keeping surpluses at home while many go hungry abroad or selling the food on world markets which will drive up domestic food prices (Cogan, 1992; Chiotti, ND; & Reilly, 1994).

Herbert and Burton (1995) have estimated that the cost of agricultural adaptation to current climate in Canada as over $1.3 Billion, and the costs of adaptation (e.g. crop insurance, irrigation, research and development) are likely to increase under climate change (with the exception of a decrease in the cost of heating fuel). Table 3 outlines some of the potential effects from policies, and points out some of the required changes.

Table 3. Climate change and its impact on policies in agriculture.

Policy	Impact of Climate Change	Confidence in Estimations	Policy Modification Required
Agricultural research	continued need	high	need to enhance research of plant and animal varieties that are • heat and stress resistant • resistant to new insects and diseases
Water policy	water availability for irrigation	medium	• irrigation policy change based on water availability forecasts • increased research to develop drought tolerant crops
Farm numbers	• increased difficulty for farmers to survive increasingly adverse conditions • increased exodus of farmers from the land • continued rural depopulation • increased reliance on program payments	high	assist the restructuring of agriculture • transition programs for those who wish to exit • restructuring of financial instruments • design market neutral programs
Soil conservation	• reduced organic material • increased incidence of soil erosion	high	• increased emphasis on soil conserving practices • continuation of the Canada-Saskatchewan Soil Conservation Program • restructure agriculture programs so as not to promote breaking of marginal land
Diversification	• continued need	medium	• continued emphasis on diversification
Trade	decreased contribution to provincial GDP as agriculture output decreases	low	• diversify provincial economy
Financial and management support	increased reliance on program payments as climate change worsens the farm situation	low	• assist restructuring of agriculture • develop market neutral programs
Inspection	• new types of livestock pests and diseases will be introduced with a milder climate • new types of crop disease and pests	low	• education of inspection and grading officers to identify potential problems • new legislation and/or regulation for crop standards and grades

Source: Miketinac in Wheaton and Wittrock, 1992.

Agriculture and Sustainability

In terms of the effect of changing crop mixes and revenues on the rest of the prairie economies, other sectors will be affected by expenditures for farm inputs and consumer goods and services. Discretionary expenditures change in direct response to changes in cash flow, hence those scenarios that produce a negative effect on prairie agriculture will pass on those negative effects to other sectors too but to a lesser degree (Arthur, 1988). While it is tempting to compare results from different sources, this should be done with caution since these studies have all been done using different assumptions and methodologies. Furthermore, most studies only take the effect of climate change into account while all other factors are held constant. Given the complexity of combining climate change models with economic and other models and the degree of uncertainty inherent in all of these models, figures and predictions that are presented as economic impacts in section III have to be interpreted accordingly.

While past experience has indicated that the agricultural sector is able to respond and adapt quickly to changes in climate, government will play a role in how the sector adapts and how quickly. Government compensation, subsidy and assistance are programs which the government uses to offer rural communities some form of economic and social security. However, if farmers on an individual level are always able to access government assistance when faced with climatic catastrophe they do not have an incentive to change their practices so that they match the climatic reality since the government will always bail them out. A balance needs to be found between government programs that help in emergencies and act as short term coping strategies versus government programs that encourage their use as an adaptive strategy (Smit, 1995; & Van Kooten, 1992).

The changing climate on the Canadian prairies could have a significant role to play on the population. Assuming that agriculture moves to more diversity, there will be an increase in available jobs. This is based on the fact that cereal production on the prairies is very mechanized, while other production, such as livestock and specialty crops are more dependent on labor. The counter argument is that if climate change has reduced the ability of the prairies to support humans, based on the quality and the quantity of resources such as water, soil, flora and fauna, then out-migration can be expected.

While temperature conditions may be favorable for growing new types of crops in the prairies, moisture deficits may preclude these new crops as an adaptation option. However, in order to adopt these new crops moisture deficits could be overcome through the use of irrigation (also an adaptive strategy). Decreasing availability of water for all users on the prairies will lead to conflicts as producers compete with recreationists, household users, electrical utilities, and the manufacturing and other industry for water for irrigation (Rosenberg, 1992; & Wittrock and Wheaton, 1992).

Recommendations

It may be possible to extract additional information from previously conducted studies to address these knowledge gaps, but it is likely that new research will need to be undertaken.

- A vulnerability analysis should be done for all three prairie provinces of the effect of climate change on agriculture and the second round effects on the other sectors of the economy. An attempt should be made to quantify the costs and benefits.

- General equilibrium models should be integrated with climate change and agricultural models in order to try and take the dynamic nature of things into account.

- Further research is needed on farm-level decision making, examining the role of climate change variables vis-a-vis societal and other forces in influencing land management adaptations.

- Although some models predict a northward movement of agriculture, further research is needed to determine the suitability of these soils to a shift in agriculture.

- Based on expectations of what climate variability and change can be expected on the prairies and how it will affect agriculture, policy needs to be analyzed and adjusted so that it acts as an incentive to farmers to adopt the appropriate management strategies and agricultural practices for the new climate reality.

- Further research is needed to determine the indirect effects of climate change; specifically the impacts on agriculture elsewhere and the effect upon Canada's competitive position in the global marketplace.

The following research questions should also be considered in future research on climate change and variability impacts on Prairie agriculture:

1. What are the attributes of climate to which agricultural systems respond?
2. Why do responses differ, and what characteristics of farming make certain types of regions more vulnerable or adaptive than others?
3. What non-climatic conditions influence the propensity to adapt?
4. What role do crop insurance, subsidies and technological development play in influencing adaptations in farming systems?
5. What are the constraints on and incentives for adaptation in the future?
6. How sustainable are land management responses to climate change?
7. How can agriculture become more sustainable to climate change?

source: Smit et. al. (1996) and Chiotti et al. (1997)

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