Canadian Agri-food Sector Adaptation to Risks and Opportunities from Climate Change

POSITION PAPER ON CLIMATE CHANGE, IMPACTS, AND ADAPTATION IN CANADIAN AGRICULTURE

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PREFACE

Climate and weather conditions are important factors for agricultural production. Variations in climate conditions, especially drought and extreme temperatures, frequently pose significant challenges to agricultural operations, and to related businesses and communities. With climate change, it is expected that many of these weather conditions will be altered. Indications are that climate change is already having an effect on farming in several Canadian regions.

Producers view climate and weather risks as one of several factors to be included in their operating strategies related to production practices and financial management. Policy makers are charged with developing programs and legislation that enhance the agri-food sector's ability to manage climate risks and take advantage of opportunities, while researchers seek to improve our understanding of the implications of climate change for the agri-food sector and to provide a sound basis for decisions on adaptive strategies. Representatives from these three groups (industry, policy, and research) work actively in C-CIARN Agriculture (Canadian Climate Impacts and Adaptation Research Network for Agriculture) and have requested an overview of the state of knowledge regarding the implications of climate change for agriculture and the prospects for adaptation in the agri-food sector.

This position paper reviews and summarizes the current state of knowledge about climate change risks and opportunities for the Canadian agri-food sector with a focus on adaptation strategies. The document also identifies research gaps and issues that need to be addressed if policy and programs for agricultural adaptation to climate change are to be timely and effective.

ACKNOWLEDGEMENTS

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HIGHLIGHTS

Climate change, manifested through climate variability and weather, will pose significant challenges and some opportunities for the Canadian agri-food sector. Extended droughts and increases in temperature appear to be the conditions causing the most concern while longer growing seasons offer potential increases in yield and diversity of crops grown. Climate and weather impacts vary widely according to region and farming system.

Many strategies exist for adapting to climate change and weather conditions. Adaptation involves government, industry, and farm level actions. Because producers adapt to climate change in conjunction with other business risk management strategies, it is important to use a "whole-farm" approach for understanding adaptation issues. Likewise, adaptation policy will be more effective if it is integrated into existing programs.

Research and policy initiatives for adaptation to climate change are relatively undeveloped for a number of reasons, including the tendency for climate change to be equated only with greenhouse gas emission reduction rather than acknowledging the need for understanding adaptation to altering conditions. Also relevant is the fact that impacts research relies mostly on "top-down" scenario-based approaches where adaptation tends to be assumed and removed from producers' lived experience.

There is need for policy-relevant research that examines producers' capacity to deal with climate and weather risks. To date, there has been little government support for research approaches focusing on capacity. However, leading non-governmental organizations such as the IPCC, the World Economic Forum and the World Food Programme are moving in that direction with their adoption of a "vulnerability perspective". This perspective features what is "known" and can accommodate diversity; it incorporates producer-based experience and knowledge, encourages integration, and builds on existing capacity.

Government ministries working for a stronger agri-food sector could enhance their capacity to develop effective climate change adaptation programs and policies by supporting research that uses the vulnerability approach.

RECOMMENDATIONS

Based on the information presented in this position paper, a number of gaps relevant to the Canadian agri-food sector have been identified in climate change adaptation research approach and support as well as government policy. Recommendations for addressing these gaps include:

Research Approach and Support

- **Employ the vulnerability approach for climate change adaptation research:**
    - **Enhance knowledge of producer' experiences with climate and weather risks and how these affect adaptation choices.**
    - **Incorporate knowledge of farm production practices and management so that linkages to existing (and future) programs and policies can be identified and acted on.**
    - **Ensure that climate scenarios and related models include agro-climatic conditions identified as relevant by the agri-food sector.**
    - **Encourage climate change related research projects to incorporate whole farm perspectives.**

- **Support research that enhances the adaptive capacity of Canadian agriculture and results in reliable products for managing climate risk and uncertainty.**

Government Policy

- **Assess current and future policies including the Agricultural Policy Framework in light of agri-food sector requirements for climate change adaptation.**

- **Improve existing climate and weather data collection and services related to them.**

- **Make climate change adaptation research a funding priority.**

EXECUTIVE SUMMARY

This position paper summarizes the current state of knowledge about climate change risks and opportunities for the Canadian agri-food sector, and provides recommendations based on an assessment of the outstanding research gaps and issues. Following an introduction to the main issues, literature is reviewed and presented according to three broad topics: Scenario-based Impact Assessments, Climate Risk Management and Adaptation Opportunities, and Vulnerability and Adaptive Capacity. The paper concludes with recommendations regarding future research and policy directions. The main points from each section of the position paper are presented in this executive summary.

1. INTRODUCTION

The phrase "climate change" is associated with the analysis, policy, and action related to increased greenhouse gas emissions and subsequent global warming. Significant human and financial resources have been devoted to implementing policy and programs related to the Kyoto Protocol. Efforts are aimed at reducing or mitigating greenhouse gas emissions to address one dimension of the climate change issue, namely the need to slow down or stabilize climate change. Concurrent with this mitigation objective is another goal, to develop and promote adaptation strategies that will reduce the adverse effects of climate change itself and moderate the risks while capturing opportunities associated with changing climate and weather conditions. However, for a number of reasons, adaptation research has often been neglected.

2. SCENARIO-BASED IMPACT ASSESSMENT

Most research into climate change impacts on agriculture and how to adapt to them is based on climate change scenarios (*i.e.* plausible future climate conditions), which in turn derive from General Circulation Models (GCMs). Climate scenarios represent a "top-down" view of climate change. Such studies begin with some assumed future climate, usually focused on changes in temperature (*i.e.* global warming). They can be used to generate estimates of future climate conditions, mainly temperature norms and some moisture attributes, at a rather coarse spatial scale. Researchers then downscale the climate model outputs to estimate future local climate and to predict agricultural impacts.

Scenario based climate projections suggest there will be both positive and negative impacts on agro-climatic properties, crop and livestock production, farming systems, and regional economies. With climate change, most regions in Canada are expected to experience warmer conditions, longer frost-free seasons, and increased evapotranspiration rates. However, projected climate conditions and associated predicted impacts vary widely across regions and farm type. Some crop yields may increase due to longer growing seasons but uncertainties exist related to accompanying moisture levels and indirect impacts from pests and diseases. Projected impacts on livestock remain largely unknown although concerns exist about increased heat stress, pest infestations, and disease rates. It is noted that future changes in climate and weather conditions have the potential to produce profound effects on soil erosion and runoff from cropland. As well, there may be potential for already sensitive agricultural ecosystems to be damaged unless they are managed even more carefully.

Scenario-based impacts on farming systems and regional economies vary widely depending on levels of adaptation among producers and other factors. Many studies assume the technology, knowledge, and capacity to adapt will be in place for future agricultural production. Little to no attention has been directed to how climate and weather risks will merge with other risk factors for the sector (*e.g.* economic and environmental conditions).

3. CLIMATE RISK MANAGEMENT AND ADAPTATION OPTIONS

Focusing on risk management and adaptation broadens the context for the discussion and provides insights into how climate and weather risk management are integrated into on-farm decision-making processes. Producers rarely deal with risks as isolated phenomena given the highly integrated nature of farming systems. Climate and weather risks are closely linked to management decisions regarding yield, input costs, and environmental factors.

Even though they may not explicitly acknowledge climate and weather conditions as an important element of their risk management strategy, producers employ adaptation strategies that lessen the risk of negative impacts. Examples include: crop and enterprise diversification, land and water resource management, alterations to livestock management, altering timing of planting, and adopting new technology (*e.g.* irrigation systems if/when water resources are available), among many others. Adaptation options such as these have been categorized according to temporal scale (long and short term measures) and according to type (technological, government program, production practices, and farm financial management).

Some researchers incorporate adaptation options into scenario based impact assessments while others feature producer perspectives on those actions. In all cases, adaptation options for climate and weather related risks form part of a business risk management strategy and vary according to farm types and locations. Understanding what adaptation is and the implications various options carry with them is an increasingly important dimension of climate change research.

There are several ways governments (often in partnership with the larger agri-food industry) can provide support for climate and weather risk management, including sponsoring programs and subsidies for action, providing information for climate and weather impact reduction, supporting research programs, and participating in crop insurance and income stabilization programs.

Issues, and therefore research, related to climate risk management and related adaptation options are wide-ranging. They often link to data and information gathered for other topics of concern, further supporting the fact that climate and weather risk management cannot be understood as an isolated component in farm decision-making, policy development, and research. A great deal remains unknown about how producers perceive climate risk and make decisions regarding adaptation strategies. As well, many existing programs and policies are relevant for adaptation strategies yet little has been done to identify opportunities for integration and mainstreaming.

4. VULNERABILITY AND ADAPTIVE CAPACITY

The IPCC notes that vulnerability to climate change is a function not only of the system's sensitivity but its ability to adapt to new climatic conditions. Generally, vulnerability increases with sensitivity and decreases with adaptive capacity, which is defined for climate change as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences."

The application of a vulnerability perspective to climate change impacts and adaptation research is still in its infancy and has the following characteristics:

- It considers a variety of stresses, both climatic and non-climatic.
- It considers not just the "what?" (the hazard) but the "on what?" (the conditions of the system exposed to the hazard).
- It is time and place specific, but with a recognition of what came before and the larger environment within which a place exists.
- It involves stakeholders.
- It takes an "inverse" approach, which starts with the system (farm/community/sector/ region) under consideration rather than a particular hazard.

Pursuing the vulnerability perspective requires closer integration of researchers from the social sciences with climate modelers and natural scientists. In scenario-based research, work begins with modeling and the role of human agency is only considered after future climate and impacts have been predicted. Research which employs the vulnerability perspective incorporates human agency at the outset, and what is relevant and potentially problematic for farmers and their capacity to deal with stresses is a key input into modeling exercises. Thus research into producer perspectives and actions (traditionally done by social scientists) receives earlier and more prominent consideration than it does in scenario-based approaches.

5. CONCLUSIONS: RESEARCH GAPS AND RECOMMENDATIONS

Based on the information presented in this position paper, a number of gaps relevant to the Canadian agri-food sector have been identified in climate change adaptation research approach and support as well as government policy. Recommendations for addressing these gaps include:

Research Approach and Support

- ♦ **Employ the vulnerability approach for climate change adaptation research:**
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1. INTRODUCTION

The history of agriculture involves a series of adaptations to a wide range of factors. Environmental conditions related to soil, water, terrain, and climate provide constraints and opportunities for agricultural production, while technological developments lead to modifications in the structure and processes of farming operations. Likewise, market factors related to input costs and prices have a dramatic effect on what commodities are produced and how/where production takes place. Public policies and programs are also major elements influencing the agri-food sector.

None of these factors remains constant and their effects are interdependent. Their changes over time represent stimuli that affect the success of farming activities and that prompt adjustments to altered circumstances. Weather and climate conditions are key determinants for success in the agri-food sector. Lobell and Asner (2003), analyze data on crop yields, temperature, precipitation, and solar radiation throughout the U.S.(1982-98) and conclude that effects from climate have been underrated and often mistakenly attributed to management practices. Variations in conditions such as length of growing season, timing of frosts, heat accumulation, precipitation, evaporation, and moisture availability all influence production and therefore economic returns to producers and agribusiness. With greenhouse-gas-induced climate change, growing conditions and climate related risks and opportunities are expected to change, and may already be changing (Rosensweig *et al.* 2000).

The purpose of this position paper is to review and summarize the current state of knowledge about climate change risks and opportunities for the Canadian agri-food sector with a focus on adaptation strategies. The document is intended to inform the research community, the agri-food industry, and policy-makers about what is known and what issues need to be acted on. Reviews of climate change and agriculture have been completed in the past. The *Canada Country Study* has an agricultural component (Brklacich *et al*., 1998) as does the more recent set of documents entitled *Climate Change Impacts and Adaptation: A Canadian Perspective* (Natural Resources Canada, 2002). In both cases, the authors point out a substantial lack of research and information regarding climate adaptation and risk management for the Canadian agri-food sector. This position paper addresses that gap and provides a thorough review of the literature and information available for researchers and policy makers. The paper also points to a new direction (the vulnerability approach) to guide climate adaptation and risk management research in a manner that will help to meet needs for improved policy and programs.

The paper begins with a review of the climate change issue and the roles of mitigation and adaptation in Canada. Climate change itself is summarized, highlighting the attributes that are important for the agri-food sector. Research based on climate scenarios is presented next, noting the estimated impacts on agro-climatic properties, crop and livestock production, farming systems, and regional economies. Another body of research related to climate risk management and adaptation opportunities is then reviewed, followed by an outline of the vulnerability and adaptive capacity approach. The paper concludes with recommendations for addressing research gaps and issues relevant for programs and policy related to climate change adaptation in the Canadian agri-food sector.

2. CLIMATE CHANGE, MITIGATION, AND ADAPTATION

For many, the phrase "climate change" is associated with the analysis, policy, and action related to increased greenhouse gas emissions and subsequent global warming. Since 1997 representatives from Canadian government departments, industrial sectors, and the research community have devoted significant human and financial resources to implementing policy and programs related to the Kyoto Protocol. Their efforts are aimed at reducing or mitigating greenhouse gas emissions to address one dimension of the climate change issue, namely the need to slow down or stabilize climate change.

Concurrent with this mitigation objective is another goal, to develop and promote adaptation strategies that will reduce the adverse effects of climate change itself and moderate the risks while capturing opportunities associated with changing climate and weather conditions (Burton *et al.,* 2002). Obligations under the *United Nations Framework Convention on Climate Change* (UNFCCC) deal partly with greenhouse gas emissions reduction and carbon sequestration (mitigation). In addition, the Convention commits parties to "formulate, implement… and regularly update…programs containing measures …to facilitate adequate adaptation to climate change" (Article 10). The UNFCCC also commits parties to "co-operate in preparing for adaptation to the impacts of climate change, develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture" (Article 4.1.c). Likewise, the *Climate Change Plan for Canada* (November 2002) is mostly about emissions reductions or mitigation, but it also includes a commitment to "develop and research approaches to adaptation planning and tool development" and to "develop increased awareness of the impacts of climate change and the need to address them in the future through adaptation".

Federal and provincial Ministers of Environment and Energy (Charlottetown, PEI, May 2002) agreed to support the development and implementation of a *National Adaptation Framework* with the following elements:

- Raise awareness of adaptation;
- Facilitate and strengthen capacity for coordinated action on adaptation;
- Incorporate adaptation into government planning processes;
- Promote and coordinate research on adaptation;
- Support networks to share knowledge; and,
- Provide methods for adaptation planning.

There has been only modest progress at best on these in the agriculture sector (SSCAF, 2003).

Climate and weather conditions are important for all sectors of the Canadian economy dependent on natural resources; and they are fundamental to crop and livestock production in the agri-food sector (Kandlikar and Risbey, 2000). Patterns of temperature, moisture, and weather conditions greatly influence plant and animal performance, inputs, management practices, yields and economic returns. As grain producer, Brett Meinert (2003) phrased it, "we harvest water and sunshine…" Adaptation to climate and weather risks therefore is implicit in the ongoing development of the agri-food sector. With climate change, some risks will be exacerbated and others moderated. Adaptation in the agri-food sector involves practices, programs, and policies that reduce vulnerabilities to climate and realize opportunities (Bryant *et al* 2000). Adaptation initiatives involve producers, agri-business, and government agencies (Adger and Kelly, 1999). The Senate Standing Committee on Agriculture and Forestry notes that "a general goal of government policies should be to encourage the adoption of opportunities to adapt to climate change…" and recommends incorporating "climate change [adaptation] into existing policies and programs…under the category of 'no regret' policies." (SSCAF, 2003:68-69).

3. CLIMATE CHANGE RISKS AND OPPORTUNITIES

Research to date has identified substantial risks and some opportunities from climate change for the agri-food sector across Canada (Brklacich *et al.,* 1998). Depictions of climate change often feature a trend for increasing temperature, suggesting the main effect will be gradual warming. For some Canadian regions this could be beneficial if it results in production opportunities from an extended growing season and increases in available heat units (Bootsma *et al*, 2004). More heat and a longer season should allow for increased flexibility in timing of operations and choice of crops or varieties, particularly on northern margins. For instance, with the development of new hybrids and varieties, Quebec and Ontario producers have been able to grow more grain corn and have expectations that soybean production could extend to more northern agricultural regions in their provinces (Bootsma *et al*., 2004; Bootsma *et al*, 2001;). Although the opportunity to extend agricultural production northward is appealing and often assumed possible (Mendelsohn *et al*, 1994), soil quality and other constraints may impede such developments (Smit and Brklacich, 1992).

The focus on temperature changes reflected in the term "global warming" tends to mask other significant alterations in conditions associated with climate change, in particular changes in the frequency, magnitude, and extent of climatic extremes such as droughts and floods (Kling *et al*., 2003). The range of possibilities leads to considerable uncertainty about the agronomic implications of climate change. This is especially true for horticultural crops where generalizing over the wide variety produced is difficult and may be compounded by alterations in other factors (eg. marketing factors, infrastructure, and available land) (Peet, 2004).

Climate is naturally variable. Figure 1 shows the inter-annual variations in an agriculturally-relevant climate attribute (to illustrate, drought severity). Agricultural systems have evolved to cope with modest variations in drought severity (within a coping range), but they are vulnerable to the extremes. Reilly *et al.* (2001:13), for example, note that variability "wreaks havoc on farmers". As Figure 1 demonstrates, with climate change, the average drought severity gradually increases but even after considerable climate change an average year is still manageable (*i.e.* it is within the coping range). However, under climate change, even without any alteration in variability, there is an increase in the frequency of very severe droughts (*i.e.* droughts that fall outside the coping range). As indicated, a one in ten year drought may now become a one in three year drought (IPCC, 2001).

While increases in heat may represent a benefit in some areas, many agricultural regions are clearly vulnerable to climate risks associated with more frequent and severe droughts, heat waves, violent storms, and flash flooding. These conditions currently represent hazards to the agri-food sector and may already be exacerbated by climate change.

It may be possible for a system to adapt to changes in average conditions and also to changes in the frequency of climate/weather extremes. Such adaptations represent a broadening of the coping range. In practical terms, such adaptation would involve technological, production, management, and financial initiatives to deal with the risks and opportunities associated with a changing climate (Smit and Skinner, 2002). Thus climate change is not only about long term gradual increases in average temperature. It includes alterations in many climate and weather conditions, many of which already constitute challenges for agriculture.

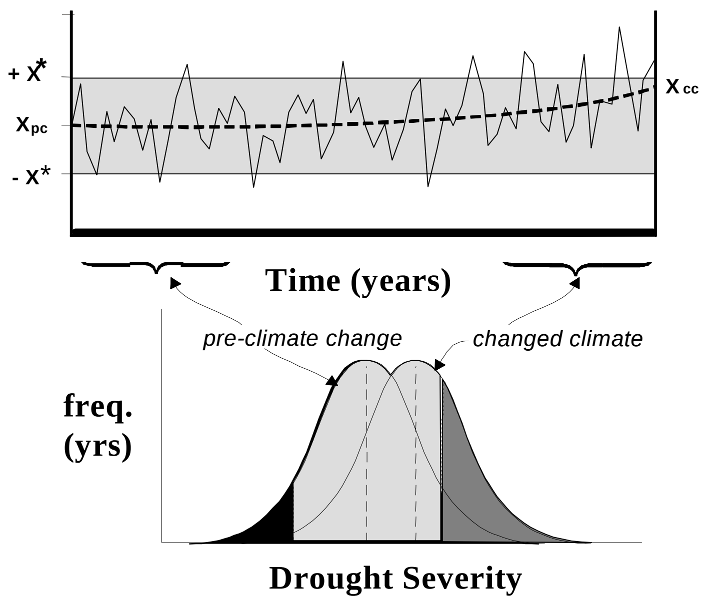

Figure 1: Climate change includes changes in extremes (after Smit et al.*, 2002)*

Climate change is often characterized as an "environmental issue" and impacts are defined in terms of temperature zones, production conditions, growing season conditions, and/or yields. Yet, for the agri-food sector, climate change is as much an "economic issue", posing risks for the financial viability of individual farming enterprises, regional agricultural sectors, and rural communities depending on agricultural activity. Also affected are agri-business firms that supply inputs, process outputs, and provide services, and the institutions that fund support programs related to agricultural production. Adaptation applies to them as well (Benioff *et al*., 1996; Adger and Kelly, 1999; Smit and Skinner, 2002).

4. SCENARIO BASED IMPACT ASSESSMENTS

One of the more common approaches for understanding impacts on agriculture and how to adapt to them is based on climate change scenarios (*i.e.* plausible future climate conditions) which in turn derive from General Circulation Models (GCMs). These models are computer programs capable of simulating the dynamics and thermodynamics of the atmosphere, ocean, land, and ice cover and can be run based on different levels of greenhouse gas concentrations (most commonly twice current CO_2 levels). In some cases, researchers incorporate scenarios reflecting economic development, energy and land use, and emissions. Several climate models are available for research into climate change impacts on the Canadian agri-food sector. (See Appendix A for a list of those referred to throughout this paper.) As Burton *et al.,*(2002) note, and as demonstrated throughout this section, impacts research is oriented to physical and biological sciences. This stands in contrast to adaptation and vulnerability studies (reviewed in sections 5 and 6) where the emphasis is on social science.

4.1 CLIMATE CHANGE SCENARIOS

Impact studies based on climate scenarios represent a "top-down" view of climate change effects (Easterling, 1996) and are subject to a number of inconsistencies (Burton *et al., 2002;* Courtois, 2004). Such studies begin with some assumed future climate usually focused on global warming (Smit *et al.*, 1988). They can be used to generate estimates of future climate, mainly temperature norms and some moisture attributes at macro spatial scales. Researchers then downscale the climate model outputs to estimate local climate and to estimate possible impacts (Reilly and Schimmelpfennig, 1999). For instance, they might indicate how certain agricultural variables (such as crop yields) would perform under a changed average year, *ceteris paribus* (Bootsma *et al*, 2004).

Uncertainty is inherent in this approach and is due to challenges in modeling variability and working with coarse resolutions (Antle, 1996; IPCC, 2001) as well as the wide range of estimated yield impacts, analytical methods, and crops studied (Reilly and Schimmelpfennig, 1999). Examples of uncertainty include how alterations in average temperature and precipitation will influence crop-relevant parameters, regional and local distributions of climate conditions and effects from inter-annual variations and extremes. Major assumptions are also made for impact analysis. For instance, impact assessments often assume that shifts in production regions are based directly on changes in agro-ecological thresholds and that stability exists in soil conditions, crop strains, technology and the political and economic environments (Reilly and Schimmelpfennig, 1999; Smit, 1991).

Scenario-based climate change assessments invariably treat adaptation options as discrete measures to incorporate into the model to offset detrimental impacts. Often such analyses yield positive outcomes, suggesting that, on balance, as long as producers make the necessary changes, the agri-food sector will see a net benefit from climate change (Easterling *et al*, 1992a; Mendelsohn *et al.,* 1994; Reilly, 1995).

Scenario-based research provides analysis for impacts on agroclimatic properties, crop and livestock production, farming systems, and regional economies. These are reviewed in the following four sub sections.

4.2. SCENARIO-BASED IMPACTS ON AGROCLIMATIC PROPERTIES

The agroclimatic properties assumed to be most important for the agri-food sector include: growing and frost free seasons, seasonal values for temperature, growing degree days, corn heat units, precipitation, and moisture deficits (Brklacich *et al.*, 1998:230). The scenario-based estimates of future agro-climatic conditions rely on attributes available from the GCMs and have tended to focus on average years with 2xCO_2.

Brklacich *et al.* (1998) conclude that most regions in **Canada** are expected to experience warmer conditions, longer frost-free seasons, and increased evapotranspiration rates:

> …there is strong consensus that global climate change will result in longer and warmer frost free periods across Canada and thereby generally enhance thermal regimes for commercial agriculture. These changes in agro-climatic conditions are not expected to impact regions on an equal basis, with the longest extensions of the frost-free season expected in Atlantic Canada. The extent to which these longer and warmer frost free seasons might benefit Canada however will in all likelihood be diminished by increases in seasonal moisture deficits across all regions and under all climate change scenarios. Hence it is crucial that all assessments of the implications of global climate change for Canadian agriculture take account of the possibility of both negative and positive impacts on agroclimatic properties. (Brklacich et al 1998: 233)

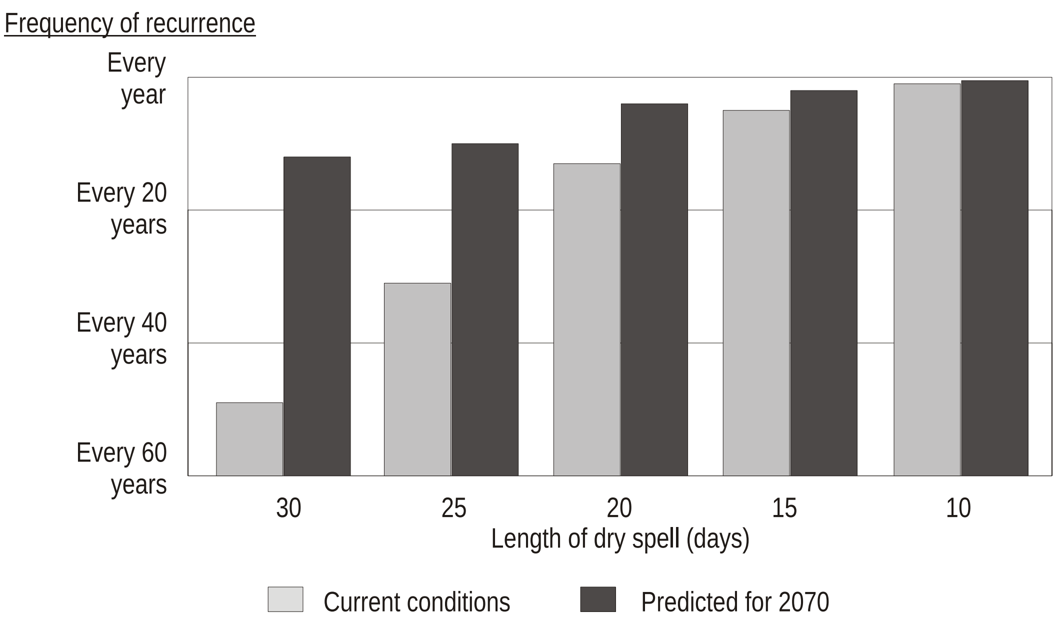

Figure 2: Frequency and Severity of Droughts in Western Canada (after Hengeveld, 2000)

Similarly, Figure 2 illustrates that the return period for severe droughts is decreased. Under current climate conditions, for example, a 30-day dry spell is expected to occur every 50 years. By 2070, dry spells of this length can be expected every 20 years. Similarly, the return period of 20-day droughts might decrease from once every 35 years to once every 15 years.

In much of **central North America**, the number of rain days is expected to decrease under most scenarios which means there is an associated risk of increased frequency of long, dry spells (Gregory *et al.*, 1997). Projections for specific Canadian regions indicate wide variation across the country. **West coast** estimates are for warmer and wetter conditions. Precipitation may increase in the winter months but decrease in the summer (B.C. Ministry of Water, Land and Air Protection, 2002). Scenario projects for the **Prairie** region indicate a return to past conditions where persistent aridity was recorded for intervals of decades or longer (Sauchyn *et al.,* 2003). More specifically, analysis of drought risks for the **southern Saskatchewan** area suggests that soil moisture conditions could become more variable with the frequency of severe drought and drought conditions dramatically increasing (Williams *et al.*, 1988).

Future conditions for **Manitoba** are similar to Saskatchewan with suggestions that winters may be warmer and have less snow, summer temperatures are expected to rise and precipitation, though reduced, may come more often in major events. It is likely that the growing season will be extended but may include more severe hail storms with the rise in extreme temperatures (Climate Change Connection, 2003). Like Manitoba, **Ontario and Quebec** are expected to have longer growing seasons (DesJarlais *et al*, 2004). Ontario will likely experience warmer winter and summer temperatures, increased number of extreme weather events (*e.g.* violent storms) and prolonged dry spells (Koshida and Avis, 1998). Quebec may have increased precipitation in northern regions and the same or slightly less in the south (Koshida and Avis, 1998).

Conditions in parts of the **Atlantic region** appear to be more difficult to project. It may be that conditions will be warmer and wetter in future years, extending the growing season and providing more heat units for crop production (Bootsma *et al.,* 2001). Precipitation levels will likely vary widely, possibly leading to drought conditions in some areas while others might be too wet (Koshida and Avis, 1998).

Although there is a great deal of uncertainty surrounding projections from climate change scenarios and their possible impacts on agroclimatic properties across Canada, various studies provide some relatively consistent results that could be taken into account. One way to apply the expected changes in agroclimatic properties is to examine the potential consequences they could have for crop and livestock production. This topic is addressed in the next sub-section.

4.3 SCENARIO-BASED IMPACTS ON CROP AND LIVESTOCK PRODUCTION

A substantial body of research goes beyond agroclimatic effects to estimate impacts for crop and livestock production in light of climate change scenarios and associated elevated levels of CO_2. This approach focuses on climate change impacts for agricultural resources and biophysical yields, usually holding other factors constant.

4.3.1 CROP YIELD AND PRODUCTION

De Jong *et al.* (1999) use the CGCM1 to determine changes in temperature and precipitation for a number of agricultural **regions across Canada**. They employ the future climate data in the EPIC (Erosion Productivity Impact Calculator) model to predict crop yields. Based on the expectation of warmer and slightly wetter climate conditions they project a one to two week advancement of planting dates for eastern and central Canada and approximately three weeks in the west. Potential outcomes for yield show no significant change for barley, wheat, and canola, while corn nitrogen fertility needs in central Canada could increase. Soybean, potatoes, and winter wheat are projected to increase substantially.

For **British Columbia**, research into climate change impacts on agriculture in the semi-arid interior valley regions has focused on irrigated crop production. Based on projections from the CGCM1, Neilsen *et al.* (2001) estimate that water demands could increase 35 per cent in the 21st century. Consequently, production will be disadvantaged unless there are improvements in water supplies and irrigation efficiencies. Neilsen *et al.* (2001) also consider potential impacts on fruit production, noting that the growing season could be extended by more than one month. Such a change could favour some apple and grape production, as would the reduction in potential harm from winter damage. However, other challenges might arise from these factors, namely harm to produce from extreme heat and from the persistence of pests able to survive a milder winter.

Climate change research for the **Prairie Region** includes several studies. Williams and Wheaton (1998) examine potential climate change impacts for Saskatchewan based on climate models from GISS and the IIASA. Biomass productivity and wind erosion potential are estimated using CA (climatic index of agricultural potential) and C (wind erosion climatic factor). Results indicate that the peak growth season would arrive earlier and there would be more risk of wind erosion in midsummer. Although increased rainfall may offset any negative impacts, suggestions are that, with further warming, trends in biomass potential would be variable across time and provincial region (Williams and Wheaton, 1998).

Later analysis of the same region produces somewhat contradictory results for crop production (McGinn *et al.*, 1999; Nyirfa and Herron, 2001). Based on climate projections from the CGCM I and EPIC (Erosion Productivity Impact Calculator) for estimating crop yields, there appear to be opportunities for wheat production in an average year related to an advance in possible seeding and harvesting dates. A potential 50 per cent increase in the number of growing days across the region is cited for 2040-2069 (McGinn et *al.*, 1999). These positive results also include effects from elevated high atmospheric CO_2. By contrast, Nyirfa and Herron (2001) use the CGCM I in conjunction with the Land Suitability Rating System (LSRS) and conclude that constraints from moisture deficits and heat will offset the advantages of predicted precipitation increases during the same period.

Brklacich and Stewart (1995) incorporate information from GISS, GFDL, and UKMO circulation models at double CO_2 concentrations for their analysis of climate change impacts for the Prairie region. They note that each model projects a different set of agroclimatic conditions and therefore varying impacts on wheat production (estimated with a CERES-wheat model):

> "Temperature increases would lengthen the frost-free season and reduce the risk of frost damage, but the higher temperatures would hasten crop maturation process and thereby suppress yields. Elevated CO_2 levels would improve water use efficiency (WUE) and provide more C for photosynthesis, and thereby tend to offset the potential negative effects of shortened crop maturation periods" (Bklacich and Stewart, 1995:155).

In addition, the authors examine the effects of specific adaptive strategies (irrigation, winter wheat conversion, and earlier seeding) producers are assumed to adopt. Irrigation appears to be the most effective (but noted as least sustainable) response. Conversion to winter wheat would be beneficial in southern sites given the possibility of more effective use of early spring moisture. Earlier seeding options, while being the easiest to implement, are the least likely to have widespread positive results because other factors (namely temperature and moisture stress) could suppress yields. Similar conclusions are presented in the work of Delcourt and van Kooten (1995), who employ a different circulation model, namely the CGCM II and focus only on study areas in southwestern Saskatchewan (part of the Palliser Triangle). Their analysis suggests substantial wheat yield loss and erosion of the farming economy.

For **Ontario and Quebec**, projected changes in agroclimatic properties (based on the use of CGCM II) may have potential benefits for corn and sorghum but likely not for wheat and soybeans produced in southern Quebec (El Maayar *et al.*, 1997; Singh *et al.*, 1998). Similar conclusions are drawn for corn yields in regions of the midwestern United States (Southworth *et al.*, 2000) where conditions are similar to southern Ontario. In this U.S. case, predictions from HadCM2 and CERES models are consistent and lead researchers to conclude that corn yields in an average year will alter significantly with northern areas experiencing gains and southern regions losses. Strzepaek *et al.* (1999) model water use and corn production using circulation models from GISS, GFDL and MPI . Their analysis is based on output from WATBAL for water supply, WEAP for water demand forecasting, and CERES-Maize, SOYGRO, and CROPWAT for crop and irrigation modeling. They conclude that the current relative abundance of water in the region will likely be maintained up to the 2020s but find progressively larger changes in the 2050s and beyond may compromise water availability for irrigation.

Based on climate models that indicate areas close to the **Great Lakes Basin** are expected to have a warmer, wetter climate (Andresen *et al.*, 2000), analysis using DAFOSYM, CERES-Maize, and SOYGRO suggests possible northward extension of crop production and dramatic increases in yields for soybeans and maize. Results employing the HadCM2 and CGCM1 indicate that yield for some forages may also improve and fruit production in the area might benefit from extensions in growing season length and seasonal heat accumulation (Winkler *et al.*, 2000). However, these results do not include potential effects from inadequate fertility and/or new pest infestations; factors that strongly affect production. Findings also rely on average temperature and precipitation rates which tend to mask site to site and year to year variability in yield (Kling *et al.*, 2003).

Such limitations were taken into account for a study on fruit production in Great Lakes Basin that includes downscaling the CGCM1 and HadCM2 to finer spatial and temporal scales (Winkler *et al.,* 2002). The authors identify the need to incorporate relevant agroclimatic factors such as the frequency and timing of threshold events (*e.g.* fall and spring freeze dates) and increased risks from pests in the analysis. When such elements are included in estimations for codling moth development, it is not certain that climate change will bring more amenable conditions for fruit production to the area (Winkler *et al.*, 2002). In fact, there is substantial evidence that Great Lakes regions may remain vulnerable to springtime cold injury and experience heavier pest infestations.

In the **Atlantic region**, Bootsma *et al.* (2001) use the CGCM1 and conclude it is likely that corn heat units will increase substantially. Using linear regression analyses to quantify the relationship between crop yields and agroclimatic indices, they project increases in yields for grain and soybean with little change indicated for barley. Also relevant to eastern Canada are findings from Belanger *et al.* (2002), who employ the same climate models to project warmer winters which may harm perennial forage crops by reducing the amount of protective snow cover and increasing the occurrence of above-freezing temperatures. At the same time having warmer temperatures in the fall could reduce the cold hardiness of perennial plants.

4.3.1.1 Additional research on possible impacts for crop production

Scenarios and climate models are not the only tools available for estimating possible climate impacts on crops from future climate change. Basing their findings on the general expectation for increases in temperature and precipitation, some researchers conclude climate change could have implications for plant disease and crop production in three ways: direct losses from diseased crops; challenges to plant disease management; and geographical distribution of plant diseases (Chakraborty *et al*., 2000). Similar factors are important for insect pests; climate change is expected to increase the migration, reproduction, feeding activity, and population dynamics of insects and mites, thereby leading to crop losses (Cammell and Knight, quoted in Lipa, 1999: 101).

Coakley *et al.* (1999) note there are serious issues regarding climate change and plant disease management. The lack of research into this issue is cause for concern, as it is for the more general topics of climate change and "pests" (both insect and plant) (Boland *et al*, 2003; Guiterrez, 2004; Coakley, 2004; Lanterman, 2002). A review of the key points indicates that precipitation has more pronounced effects on plant disease than temperature, yet current CGMs cannot provide the necessary details on precipitation events. Also challenging is the difference in temporal and spatial scales for plant disease and climate models (Chakraborty *et al*., 2000).

Given the projected changes in precipitation and temperature for Ontario, climate change is expected to affect the incidence and severity of plant diseases there in a number of ways, including the survival of pathogens; the rate of disease progress during a growing season; and the duration of the annual epidemic in relation to the host plant (Boland *et al* 2003). These authors provide a substantive review of possible impacts from biotic (eg. fungi, bacteria, viruses, nematodes, and phytoplasmas) and abiotic (eg. nutrient deficiencies, air pollutants, and temperature and moisture extremes) diseases under altered climate and weather conditions. Appendix 1 in their report provides a "subjective" interpretation of the estimated effect for 112 diseases related to field and horticultural crops. According to their assessment approximately 63 percent of the diseases listed may become more problematic for the relevant crop. In contrast, approximately 32 per cent of the diseases listed may turn out to be less challenging than they currently are. Roughly five per cent are likely not to change in either direction.

All crop production entails some degree of pest, disease, and nutrient management. Research has been conducted into how such practices might be and are affected by different climate and weather conditions. For instance, Archambault *et al.* (2001) investigate changes in the efficacy of commonly used herbicides under increased temperature and CO_2 concentrations based on controlled experiments. They conclude that although there is a potential for herbicides to be less effective, the possible increase in crop yield may, in fact, offset any negative outcome. Ziska (2004) also addresses questions regarding weed persistence in changing climatic conditions and finds that invasive weed species show a strong growth response to recent and projected increases in atmospheric CO2 combined with weakened efficacy of chemical control. Pattey *et al.* (2001) conclude a weather component is advisable for effective nitrogen management in corn production, information that takes on more importance in light of potential change to climate and weather conditions.

Crop production eventually results in foodstuffs for human consumption. Issues related to the quality of food products can also be a climate change issue. Research indicates that crops grown in elevated CO_2 levels may lack micronutrients essential for human health (Lawton, 2002). This could have negative effects from the direct ingestion of plants deficient in trace minerals such as iron, zinc, chromium and magnesium. It also has serious implications for human consumption of food created from animal products, if those animals are likewise being fed material that is deficient in micronutrients (Loladze, 2002).

Food processors are concerned about future impacts on crop quality from changes in climate and weather conditions. Sapirstein *et al.* (2002) are currently engaged in research examining wheat grade and quality response to growing season weather variation in the **Prairie region**. They plan on assessing the effects of climate change on wheat, noting:

> "(Quality) is a major concern for wheat customers, who require a reliable source of wheat of consistent processing and end-product quality, from shipment to shipment, and from year to year. When unfavourable weather conditions impact negatively on wheat quality, the costs are both direct (downgraded wheat, reduced producer income) and indirect (inability to meet customer specifications, loss of credibility and reputation)."
>
> (Sapirstein *et al.*, 2002)

Scenario-based and other future impact assessments for crop production constitute the bulk of climate change impact and adaptation research to date. Results demonstrate wide variation in outcomes depending on the models employed and assumptions made. However, it is clear that climate change poses serious risks and some opportunities for the Canadian agri-food industry. The next sub-section considers how forage and livestock production might be affected.

4.3.2 FORAGE AND LIVESTOCK PRODUCTION

Researchers have not used climate models and scenarios to project direct impacts on livestock. They have, however, employed them for examining possible impacts on forage production (Adams *et al.,* 2003) and grassland sustainability. Both are important factors for livestock production. For instance, Baker *et al.* (1993) assess potential effects on ecosystem processes and cattle production in U.S. rangelands incorporating output from GFDL, GISS, and UKMO into various ecosystem simulation models. Their analysis for the more northern regions projects a ten per cent decrease in soil organic matter with an increase in nitrogen available for plant uptake. For cattle grazing, this could have positive results related to using more forages and relying less on food supplements, especially in the spring months. However, the authors raise questions about the long term sustainability of such systems given the loss of organic matter in the soil and increased variability in plant production (Baker *et al.*, 1993).

Cohen *et al.,* (2002) use the GCM1 and a forage production model, GrassGro Decision Support System (DSS) to estimate the effects of projected climate conditions on livestock production in three **Saskatchewan regions**. Their analysis includes different adaptation strategies related to choice of plants in pasture mixes. Results demonstrate strong variability across regions and plant type but indicate some grazing systems in Saskatchewan may benefit from climate change.

4.3.2.1 Additional research on possible impacts on forage and livestock production

As noted for crop production, impacts assessments have also been made using more general attributes of future climate change. For instance, through modifying levels of carbon dioxide, nitrogen deposition, precipitation, and temperature in experimental plots, Zavaleta *et al.* (2003) claim changes to grassland diversity (and therefore grazing availability) may be rapid. The authors replicate plausible future conditions and discover that while small increases in temperature had no obvious effect, additional CO_2 or nitrogen rapidly decrease species diversity. As well their results show how the effects of combined treatments are additive. For example, plots that received both CO_2 and nitrogen exhibited twice the decrease in diversity, compared to plots that received just one of the treatments. Indications that soil moisture can increase when the number of species declines were also noted. Their work confirms the importance of considering many climate change factors simultaneously (Zavaleta *et al.*, 2003).

Future climate conditions also have direct implications for livestock production (Wolfe, undated). Increases in heat stress for instance could result in lower weight gains and milk production in cattle/cows, lower conception rates, and substantial losses in poultry production (Kleinedist *et al.*, 1993; Adams et *al.*, 1998 in Kling *et al.*, 2003). As well, increases in extreme events (*e.g.* violent storms and flooding) might result in livestock losses (Kling *et al.*, 2003) and high day time temperatures can reduce total grazing time (Owensby *et al.,* 1996). Water supplies for livestock can be negatively affected through changes in quantity and quality. In extreme drought conditions, the potential for water to become toxic from sulphur and Cyanobacteria (blue-green algae) creates serious problems for cattle production (PFRA, 2003).

Charron and Waltner-Toews (2003) review the potential risks from climate change for livestock production regarding animal diseases. Table 1, modified from Charron and Waltner-Toews (2003: xvii-xxii), summarizes some of the possible disease outcomes for livestock related to altered climate and weather conditions.

Charron and Waltner-Toews (2003) note that alterations in rainfall patterns and temperatures affect the chances for survival and enhancement of insect vectors (ticks, mosquitoes) and associated diseases previously considered exotic or rare (West Nile, *leishmaniasis*). Milder winters can reduce the prevalence of some problems, such as pneumonia in adult cattle. However, there are greater chances of many more increasing as several diseases in young livestock (*e.g.* pneumonia and diarrhea) respond to rapid changes in temperature and moisture rather than to slowly increasing (or decreasing) averages. Milder winters can also influence parasite survival in and on animals, adding to existing parasite loads. Livestock may be also be affected by contaminated run-off in watersheds where heavy rainfalls (and/or flooding after drought) flush bacteria and parasites into water systems.

Table 1: Potential effects of climate change on vector and non-vectorborne infectious diseases in animals

Disease Agent	Animals at Risk	Transmission	Effects of Climate Variability and Change
Bacterial Diseases			
Anthrax *(Bacillus anthracis)*	Domestic animals (especially herbivores)	Water-borne, food-borne, inhalation	Spores are highly resistant to altered conditions. Improved environmental conditions for dissemination and concentration of spores.
E. coli enteritis (*Escherichia coli*)	Livestock (calves, lambs, kids, pigs, foals)	Water-borne, food-borne	Stress due to environmental conditions precipitates disease. Flooding can increase distribution.
Leptospirosis (*Leptospirosis spp.)*	Cattle, horses, swine	Water-borne	Improved environmental conditions for proliferation of organism. Flooding can increase distribution.
Salmonellosis (*Salmonella spp.)*	Livestock	Water-borne and food-borne	Organism proliferates in warmer conditions. Flooding can increase distribution.
Tuberculosis (*Mycobacterium bovis*)	Livestock	Inhalation and food-borne	Host's ranges might expand. Survives well in cold, damp conditions.
Yersiniosis (*Yersina enterocolitica, Yersinia pseudotuberculosis*)	Sheeps, pigs, goats	Water-borne and food-borne	Stress due to environmental conditions precipitates disease. Flooding can increase distribution.
Viral Diseases			
Influenza A (*Orthomyxovirus*)	Pigs, poultry, waterfowl, horses	Aerosol or direct	Potential increase in habitat, range and abundance of reservoir hosts increases risk of interspecies transmission.
Bluetongue (*Obivirus*)	Sheep, domestic deer	Not applicable	Altered geographic distribution of vector species. Enhanced vector competence, potential for creating new vector species, increased availability of breeding sites for vectors, increased passive air-borne dispersal of vector.

4.3.3 SOIL RESOURCES

The Soil and Water Conservation Society supported research investigating likely impacts on soil erosion from future climate conditions (Nearing *et al*, 2004). Although their focus is on the United States, results are meaningful for Canada. Using the CGCM1 and HadCM models, researchers focus on precipitation rates and conclude that projected changes have "the potential to produce profound effects on soil erosion and runoff from cropland" (SWCS, 2003:16). Also significant are the effects from increased storm intensity especially for row-crop production systems. The report goes on to note that once soil is destabilized by an "extreme erosion episode" it becomes more vulnerable to subsequent smaller events, leading to even greater negative results (SWCS, 2003).

Thorpe *et al.* (2001) base their research on three GCM scenarios (CGCM1, HadCM3, and ECHAM4) for future climate conditions (2050) and find approximate regions in U.S. Great Plains with analogous climates for comparison. They conclude that climate change will likely alter possibilities for **Prairie region** farming systems, especially in certain areas. In particular they note that open grasslands within sandy-soil regions may be infiltrated by forested areas and that warm-season plant species are likely to increase in grassland and elsewhere. It is uncertain what effect these developments will have on grazing capacity although increases are possible (depending on moisture levels). The small amount of cultivation currently in place would have to be managed very carefully given soil conditions. Guo (2000) broadens the scope of impact assessment in the Great Plains to issues of biodiversity conservation in agroecosystems. Projections for a warmer and drier climate from NCAR, NASA, NOAA, and CSIRO circulation models are integrated with the SEEDSCAPE model, developed specifically for unique features in Great Plains' landscapes. They conclude that projected climate conditions present serious challenges to maintaining natural areas and diversity, leading to negative results for agroecosystem sustainability in the region.

Climate change scenarios suggest substantial challenges and some benefits for crop and livestock production in Canada. The potential impacts vary widely across regions and commodity type. Implications from possible changes in specific aspects of farm production will have consequences for farming systems and their related regional economies. These are reviewed in the next sub-section.

4.4 SCENARIO-BASED IMPACTS ON FARMING SYSTEMS AND REGIONAL ECONOMIES

Climate and weather impacts on crop and livestock production inevitably have consequences for the regional economies within which farming systems function. Assessments for climate change on the North American agricultural economy suggest impacts may be minimal when compared to less developed nations (Wolfe, undated). The IPCC reports with "high confidence" that for North America, "small to moderate climate change will not imperil food and fibre production" while cautioning there will likely be wide variation in impacts within the continent (IPCC, 2001:56). For the U.S., Reilly *et al.* (2001) use Hadley and Canadian models to determine the likelihood of extreme events (more hot days and fewer cold days; more heavy rain or longer droughts) and assess economic results. Assuming producers make necessary adaptations, they conclude climate change in the U.S. will have an overall positive effect on production with a subsequent drop in prices likely leading to challenges for producers (especially those who do not practice adaptation). However Adams *et al* (2003:131) using the RegCM, note that positive predictions for climate change impacts are highly questionable given that "assessments based on finer scale climatological information consistently yields a less favourable assessment of the implications of climate change".

Reinsborough (2003) applies a Ricardian analysis for climate change scenarios for Canada and incorporates projections from the CGCM1. This approach assumes spatial associations between temperature and other climate norms and agricultural land values will apply under changed climate, reflecting autonomous adaptations in the agri-food sector. Her work builds on U.S. analysis by Mendelsohn *et al.* (1994) that concludes there may be overall benefits to the agricultural economy with projected climate change. Their findings are based on the balancing out of cropland impacts (which appear to result in four to five per cent losses) versus crop revenue impacts (which appear to result in one per cent gains). According to Reinsborough, results are much more uncertain. She finds gross agricultural revenue under climate change scenarios could improve or decline by 6.4 per cent. Such a large margin of error is exacerbated with the difficulties encountered when incorporating realistic adaptation costs (Reinsborough, 2003).

Reinsborough's analysis follows other work on climate change impacts on Canadian agricultural economy in terms of costs/benefits. Cline (1992), Tol (1995), and Kane *et al.* (1992) report negative results for the agri-food sector from climate change impacts while Nordhaus and Boyer (2000) suggest a modest benefit. Reilly *et al.* (1993) also project net benefits for Canada as long as adaptation options are pursued and CO_2 fertilization is incorporated in the scenario. Weber and Hauser (2003) who downscale projections from the CGCMII concur with Reilly *et al (*1993). They base their conclusions on an improved agricultural GDP (from increases in land values) in all provinces suggesting Reinsborough is too pessimistic.

Much of the research relevant to climate change impacts on Canadian farming systems and regional economies has been for prairie regions where climate change is predicted to have major impacts (Chiotti, 1998). Because agriculture plays an important economic role in the area, stresses and opportunities for the sector are considered significant (Cloutis *et al.*, 2001). Among the first assessments of potential climate change effects on prairie agriculture is the work of Arthur and Abizadeh (1988). Their analysis relies on the GFDL and GISS circulation models for climate change and the VSMB (Versatile Soil Moisture Budget) for determining crop responses. Their analysis builds on earlier work by William *et al.* (1987, cited in Arthur and Abizadeh, 1988) who conclude substantial losses will ensue for the sector. Arthur and Abizadeh (1988) note that, as long as adjustments are made to take advantage of potential opportunities from these changed conditions, the outcomes could be positive (especially in northern areas). Schweger and Hooey (1991) use the GISS and IISA output to estimate effects on soil erosion and conclude that there are serious concerns of escalating erosion and salinity in the Prairies connected to potential increases in moisture deficits.

Changes in growing conditions associated with future climate and weather conditions would have direct effects on the viability of **Ontario** farming systems. Two studies have assessed the potential impacts in that province. In one study, Brklacich and Smit (1992) apply GISS for the climate model and a Cropping Budget System Model in their analysis. They note that extended frost free seasons and more variable precipitation will likely take place and pose considerable risks for crop production in Ontario. Reductions in moisture levels may offset any advantages from increased growing seasons, resulting in fluctuating farm income levels and reduced capacity for food production in the province. In the other Ontario study, Brklacich *et al.* (1997) emphasize producers' adaptation responses to determine possible impacts from altered climate and weather conditions. The authors combine a number of climate change scenarios to produce a mid-range depiction of plausible climate changes for a specific region in Ontario. Producers from two types of farming systems (livestock and diversified) responded to the future scenarios in terms of how they might alter their farming systems to take advantage of conditions or lessen potential risks. Results suggest that adaptation options would be pursued with livestock operators (whose farms tended to be larger than diversified operations) potentially adopting a wider range of actions than diversified farmers.

Kling *et al.* (2003) base their assessments for climate change effects on farming systems on two GCMs, the PCM and HadCM3. They note that risks to producers would inevitably result from increasing year to year climate variability. This confirms findings from Brklacich and Smit (1992), who estimate there will be greater fluctuations in farm profits resulting from variability in precipitation and extended frost-free seasons. Kling *et al.* (2003) also suggest small to medium size operations will be more disadvantaged in higher risk circumstances.

Projections from climate change scenarios have been used to assess future possibilities for farming systems in specific agricultural regions of the Annapolis Valley in **Nova Scotia** (Mehlman, 2003). Applying the CGCM1 and a statistical downloading model (SDSM), future conditions (including precipitation, frost-free days, hot days and extremely hot days) were estimated for three future time periods. In general, spring months in the farming areas are expected to be warmer and drier while summer, autumn, and winter months will likely be warmer and wetter. Indications are that the fall might have more extreme events that coincide with hurricane season and winter might have up to 20 per cent increase in the days above freezing. The potential increase in growing season length suggests positive outcomes for faming systems but these may be offset by negative results associated with either too much or too little moisture and extreme events. Because fruit production is an important aspect of Annapolis Valley farming systems, changes in frost free days, environments for over-wintering pests, risks from flooding and violent storms are of major concern (Erith, 2003).

Scenario-based modeling studies highlight future challenges and opportunities for the Canadian agri-food sector whether at the level of farm production or for the broader agricultural economy. How these challenges and opportunities are met depends in large part on producer and institutional adaptive strategies and risk management. Agricultural production has always taken place in an environment of inherently variable and uncertain weather conditions. Climate change, including increases in extreme events, may exacerbate the negative impacts from these conditions. Insights into how such challenges can be met are found in research on climate risk management and possible adaptation options. These are discussed in the next section.

5. CLIMATE RISK MANAGEMENT AND ADAPTATION OPPORTUNITIES

This section summarizes research on climate risk management and adaptation options and broadens the context for the discussion by demonstrating how climate and weather risk management are integrated into on-farm decision-making processes.

Managing risk is a key element of all businesses and agricultural operations are no exception. Producers rarely deal with risks as isolated phenomena given the highly integrated nature of farming systems (Brklacich *et al.*, 1997). Climate and weather risks are closely linked to management decisions regarding yield, input costs, and environmental factors (C-CIARN Agriculture 2003; Tyrchniewicz, 2003.) It is not surprising, therefore, that approximately half of Canadian producers surveyed in 2001 do not consider future climate change as having a separate, identifiable impact when asked: "What do you think the impact of climate change will be on Canadian agriculture?" (Aubin *et al.,* 2003). Producers manage risks and pursue opportunities related to climate and weather conditions as an implicit element of their business decision-making process.

Risk is usually defined in terms of the probability of a consequence and its magnitude (Willows and Connell, 2003); it encompasses both the likelihood that a certain state or event will occur and that it will have consequences of varying importance.

5.1 RISK PERCEPTION AND MANAGEMENT

Risk perception is usually considered a first step in risk management. Conventional wisdom suggests that before producers take steps to lessen impacts from potential stresses, they need to acknowledge such stresses exist. However, research indicates the situation is not that straightforward as the following examples illustrate.

Producers' perceptions of climate risk appear to vary by commodity (USDA, 1999). Reid (2003) notes that producers in southwestern Ontario are more likely to view climate as a risk if their operations are more vulnerable to it. Thus cash crop producers voiced more concern about impacts from climate change than livestock operators did when taking part in focus group discussions. Generally speaking, researchers note that Canadian producers think the "industry" has provided and will continue to furnish adequate technological solutions to meet a variety of risks, including stress from climate and weather conditions (Brklacich *et al*, 1997; Bryant *et al.*, 2004, 2000; Holloway and Ilbery, 1996; Smit *et al.* 2000b).

Even though they may not explicitly acknowledge climate and weather risks as an important element of their management strategy, studies indicate producers do take past performance (linked to agroclimatic conditions) into account when making production decisions. Working with producers in southwest Montreal region of Quebec, Andre and Bryant (2001) find that although producers generally do not view climate change as an important issue, climate variability is intrinsically integrated into their decision-making process. Smit *et al.* (1997) document close connections between corn hybrid selection and weather conditions the year prior to planting. Easterling (1996) reports that farmers in certain regions of the United States tend to recognize weather risks as substantial and modify their operations accordingly. Responses from central Canadian producers indicate a similar attitude. In this case, changing climate and weather conditions (primarily increasing heat and dryness) led producers to adopt more conservation tillage, use different plant varieties and hybrids, and install irrigation systems, among other practices (C-CIARN Agriculture, 2002).

Prairie region producers also alter management practices to adapt to changing conditions. Some examples include increasing forage production, adding livestock to their farm operations, and introducing native grasses into grazing systems (C-CIARN Agriculture, 2003). According to Sauchyn (2003), more than 60 per cent of Saskatchewan farmers surveyed indicate they are preparing for climate change in response to current alterations in climate and weather conditions. Sugar beet growers in the prairie region have acted on their concerns about current risks from climate and weather conditions by investing resources in research to improve production under persistent drought conditions. In particular, they have collaborated on research into the impact of short-term weather events on pesticide, herbicide, fungicide and fertilizer applications, nitrogen management, harvesting and long-term storage of sugar beets after harvest, irrigation management, and increased conservation tillage (Tokariuk, 2003).

Risk management actions can be categorized according to four types, namely risk reduction (for example spreading risk across a diversity of crops or farm enterprises); risk hedging (typified by actions such as maintaining reserves); risk transfer (as in using crop or other forms of insurance) and risk mitigation (for instance accepting a disaster payment from government sources) (Wandel and Smit, 2000). Producers' ability to manage risk depends largely on the adaptation options available to them. Understanding what adaptation is and the implications various options carry with them is an increasingly important dimension of climate change research (MacIver and Dallmeier, 2000).

5.2 ADAPTATION OPTIONS FOR MANAGING CLIMATE AND WEATHER RISKS

Climate change adaptation refers to adjustments in management strategies to actual or expected climatic conditions or their effects, in order to reduce risks or realize opportunities. They can take many forms, can occur at different scales, and can be undertaken by different agents (producers, agribusiness, industry organizations, and governments). Adaptations are not necessarily discrete technical measures, but are modifications to farm practices and public level policies with respect to multiple (climatic and non-climatic) stimuli and conditions.

Four categories of research relate to adaptation options and climate risk management: adaptation and impact assessment; typologies of adaptation strategies; adaptation from the producers' perspective; and the role of the state and industry in adaptation.

5.2.1 ADAPTATION AND IMPACT ASSESSMENT

Some climate change researchers incorporate adaptation choices into their assessment of "impacts", recognizing that the severity of climate change risk depends on producers' and other agri-food sector players' responses. Implicit in such models is producers' "clairvoyance or perfect knowledge", that is, climate changes are completely known in advance and perfect adaptations are instantaneously adopted (Adams *et al* 2003). This "smart farmer" (Easterling *et al,* 1992) approach stands in contrast to the equally unlikely potential situation where producers make absolutely no changes in light of altered climate and weather conditions (Adam *et al.* 2003). Assumptions regarding adaptation add another level of uncertainty to many scenario based impact assessments for agriculture.

McKenney *et al.* (1992) provide analysis that assumes farmers' adaptation responses for the MINK (Missouri, Iowa, Nebraska, and Kansas) region in United States. Using the EPIC model, they create a future baseline for crop productivity in the year 2030 that reflects changes based on technological advances. These new technologies include several crop breeding improvements leading to higher yields, more efficient chemical conversions, and earlier leaf development. Also assumed are projected improvements in pest control and harvesting techniques (reducing losses). In some cases additional adjustments are used, for instance crop substitution and additions, alterations in planting dates, and more efficient irrigation. With these assumed conditions, outcomes for three of four major crops (soybean, wheat and sorghum) suggest enhanced performance in 2030 under climate change while corn yields are projected to decline. Without adaptations and adjustments, all yields are projected to decline (McKenney *et al.*, 1992).

Similarly, Easterling *et al.* (1992b) study the effectiveness of adaptation and adjustments at the farm level by running impact models (EPIC) for future climate scenarios. They compare effects on costs and revenues for cases with and those without alterations in farm production practices. For the most part, the assumed adjustments and adaptations to projected climate conditions offset the otherwise negative impacts, even when increased input costs are incorporated in the analysis. Easterling *et al.* (1997) also estimate the effects shelterbelts will have for grain production under altered climate conditions in the Great Plains region of U.S. Using the EPIC model with projected climate features (precipitation, temperature, and wind speed), the authors find the "shelterbelt effect" to be positive, especially for regions with severe precipitation deficiency and highly increased wind speeds.

Research conducted for the Canadian Prairies, based on modeling for an average year, concludes that adopting management strategies (such as changing to a different crop and earlier seeding) makes a substantially positive difference with few exceptions (Cloutis et al., 2001). Antle *et al* (2003) draw similar conclusions using data from Saskatchewan in their impact assessments for Great Plains agriculture. Nagy (2001) reports on the possible consequences for energy use in farming systems in the region when two different adaptation options are introduced into the model, namely diversifying crops and altering nitrogen use. The PCEM (Prairie Crop Energy Module) was modified to include increased acreages of two new crops-chickpeas and dry beans. Results indicate that introducing these crops into rotation may lead to altered farm practices, namely reducing nitrogen and energy use (Nagy, 2001).

5.2.2 TYPOLOGIES OF ADAPTATION STRATEGIES

Early work in identifying types of practices relies on designating short and long term measures to counteract the impact of drought in the Great Plains region of North America (Rosenberg, 1981). The latter include minimum tillage, snow management, irrigation scheduling, microclimate modification through windbreaks, diversifying crops, improved production practices (*e.g.* crop rotation, alternative planting methods, timing of fertilization), and crop breeding. Also using short and long term categorization, but in more recent documentation, Kurukulasuriya and Rosenthal (2003), generate a "matrix of adaptations" for agriculture applicable on a global scale. Included in short term options are a variety of farm level responses such as crop insurance, diversification, adjustments to the timing of farm operations, changes in cropping intensity, alterations in livestock management practices, conservation tillage, and efficient water use. Long term strategies tend to focus on industry and state action. For instance, the authors note the need for technological developments, agricultural pricing and market reforms, trade promotion, enhanced extension services, weather forecasting mechanisms, and a general strengthening of institutional and decision-making structures.

Without reference to duration, Smit and Skinner (2002) present a comprehensive account of possible adaptation options for Canadian agriculture. This is reproduced in Table 2. In this case the authors organize their findings according to four possible types: the first two (technological developments and government programs and insurance) apply mainly to options at the industry and state level while

Table 2: Main types and selected examples of adaptation options in Canadian agriculture

<u>TECHNOLOGICAL DEVELOPMENTS</u>

Crop Development

- Develop new crop varieties, including hybrids, to increase the tolerance and suitability of plants to temperature, moisture and other relevant climatic conditions.

Weather and Climate Information Systems

- Develop early warning systems that provide daily weather predictions and seasonal forecasts.

Resource Management Innovations

- Develop water management innovations, including irrigation, to address the risk of moisture deficiencies and increasing frequency of droughts.
- Develop farm-level resource management innovations to address the risk associated with changing temperature, moisture and other relevant climatic conditions.

<u>GOVERNMENT PROGRAMS AND INSURANCE</u>

Agricultural Subsidy and Support Programs

- Modify crop insurance programs to influence farm-level risk management strategies with respect to climate-related loss of crop yields.
- Change investment in established income stabilization programs to influence farm-level risk management strategies with respect to climate-related income loss.
- Modify subsidy, support and incentive programs to influence farm-level production practices and financial management.
- Change *ad hoc* compensation and assistance programs to share publicly the risk of farm-level income loss associated with disasters and extreme events.

Private Insurance

- Develop private insurance to reduce climate-related risks to farm-level production, infrastructure and income.

Resource Management Programs

- Develop and implement policies and programs to influence farm-level land and water resource use and management practices in light of changing climate conditions.

<u>FARM PRODUCTION PRACTICES</u>

Farm Production

- Diversify crop types and varieties, including crop substitution, to address the environmental variations and economic risks associated with climate change.
- Diversify livestock types and varieties to address the environmental variations and economic risks associated with climate change.
- Change the intensification of production to address the environmental variations and economic risks associated with climate change.

Land Use

- Change the location of crop and livestock production to address the environmental variations and economic risks associated with climate change.
- Use alternative fallow and tillage practices to address climate change-related moisture and nutrient deficiencies.

Land Topography

- Change land topography to address the moisture deficiencies associated with climate change and reduce the risk of farm land degradation.

Irrigation

- Implement irrigation practices to address the moisture deficiencies associated with climate change and reduce the risk of income loss due to recurring drought.

Timing of Operations

- Change timing of farm operations to address the changing duration of growing seasons and associated changes in temperature and moisture.

<u>FARM FINANCIAL MANAGEMENT</u>

Crop Insurance

- Purchase crop insurance to reduce the risks of climate-related income loss.

Crop Shares and Futures

- Invest in crop shares and futures to reduce the risks of climate-related income loss.

Income Stabilization Programs

- Participate in income stabilization programs to reduce the risk of income loss due to changing climate conditions and variability.

Household Income

- Diversify source of household income in order to address the risk of climate-related income loss.

the last two (farm production practices and farm financial management) focus on farm level management.

Details in Table 2 confirm that there are diverse adaptation options available for producers whose decisions are multi-dimensional by nature and will ultimately depend on what is feasible and realistic (Andre and Bryant, 2001; Bryant *et al.*, 2000). Many of the choices available are also closely linked to practices already in place for maintaining environmental sustainability. Acknowledging the connections between "sustainable agriculture" practices and climate change adaptation helps to streamline policy and programs for both issues (Wall and Smit, 2004).

5.2.3 ADAPTATION FROM PRODUCERS' PERSPECTIVES

Researchers have asked producers to identify changes to their production practices that result in benefits when faced with recent climate and weather risks. Examples from Alberta, Saskatchewan and Manitoba include crop and enterprise diversification, land and water management, and livestock management (C-CIARN Agriculture 2003:6). Details are summarized in Table 3.

Similar information from Ontario producers has also been documented (C-CIARN Agriculture 2002). In this case, producers perceive that climate and weather conditions have changed noticeably in the past five years. Among other actions, their responses to such conditions include:

- growing different crops and or crop varieties
- altering tile drainage
- employing conservation tillage
- changing timing of planting
- installing irrigation systems

Also in Ontario, but with reference to soybean production only, Smithers and Blay-Palmer (2001) identify farm production practices that producers have adapted, thereby reducing risks from specific climate stresses. Strategies include planting new or improved crop varieties that stand up under adverse climate and weather conditions, adopting crop rotation, and altering the timing of planting. At the community level, different tactics have been used. In southern Ontario, for instance, producers joined forces with local water managers and developed a framework for participatory water management committees to ensure both the fair sharing principle and the maintenance of flows for ecosystem services (Shortt *et al.*, 2004) These "irrigation advisory committees" were formed to deal with recent decreases in streamflows and increased water takings for irrigation. A number of similar committees have been formed in neighbouring areas where drought conditions prevail (Shortt *et al.*, 2004).

Processing tomato producers in southwestern Ontario adopt measures to increase their production efficiency. Some of their strategies include practices that have reduced the impact of extended droughts (AAFC, 2003b). These include improved irrigation systems adapted from Australia where conditions are much drier than Ontario. In 2002 season, one of the driest years in history, Ontario tomato growers with the new system had their second highest yield ever (AAFC, 2003b).

Other researchers investigate specific adaptation options to explore their implications for practice and policy. Bradshaw and Dolan (2001), for instance, identify several constraints to crop diversification including new and additional costs associated with technology required for different production systems, the pressure to specialize for meeting economies of scale, better returns from diversifying "off the farm" through pluriactivity, and biophysical and locational limitations related to soil type and

Table 3: Summary of how some producers meet the challenges from climate change

Diversify Crops

- More perennial crops (eg. forages) are grown, thus improving drought tolerance by enhancing soil quality and moisture retention
- Where possible, some producers are re-introducing native grasses for pasturing. These grasses are drought resistant when rotational grazing is practiced on them.
- Many prairie producers are moving away from solid wheat production and growing a wide variety of new crops (eg. pulses) that are more drought resistant.
- A diversity of crop types and varieties are grown in rotation and in different areas of farm properties. This spreads the risk of losing an entire year's production since conditions can vary across fairly small areas and different crops vary in how they respond to those conditions.
- When possible, some producers also stagger their seeding and therefore harvesting dates by choosing a variety of crops that require a range of growing conditions so that crops are at different stages (and therefore more or less vulnerable) if and when climate/weather conditions start having a negative impact.

Diversify enterprises within one farming operation

- Many producers are including more livestock in their operations to make use of increased forage production and to add value on the farm.

Land Resource Management

- Conservation tillage practices were cited by all producers as having several positive outcomes for reducing risks from drought. These include: reducing soil erosion; enhancing moisture retention; and minimizing soil impaction.
- Conservation tillage is also credited with limiting damage from run off and wash outs during flooding.
- Some producers are enhancing established shelterbelts and/or adding new ones. This can reduce negative impacts from drought by maintaining water tables, increasing biomass in soil, and ensuring surface moisture is kept on the land. Shelterbelts also provide protection from heat and wind for livestock, and can increase the heat units in adjacent fields.
- Some producers cut stubble at different heights to trap snow on field surfaces thereby enhancing spring moisture levels in the soil.

Water Resource Management

- The increase in drought conditions is leading to more interest in irrigation. Some producers are adopting newer, more efficient systems and timing for applications to avoid waste.
- Sloughs and ponds are managed to ensure water is captured and protected as much as possible.

Livestock management

- Some producers who were affected by drought arranged to move some cattle out for winter feeding.
- In some cases, intensive grazing leads to doubling the number of cattle on same acreage, increasing economic returns.

distance from markets. Despite such barriers, crop diversification in some regions of Canada (*e.g.* Prairies) has taken place when viewed at the regional scale. However, at the individual farm level, there is little evidence that producers employ diversification tactics when faced with financial and production risks (Bradshaw and Dolan, 2001). Analysis of crop diversity on prairie farms from 1994 to 2000 indicates a decline of 4.2 per cent and is more evident on small to medium sized enterprises. Similar results have been noted for European agriculture (EU Commission, 2001). Policy and programs encouraging producers to diversify their farm operations need to take into account the fact that other factors can work against such actions.

Climate related adaptation options for producers form part of their business risk management strategy and vary according to farm types and locations. Many options depend directly on government initiatives and programs, technology development, and financial opportunities beyond the farm gate. For instance, producers' ability to grow crops bred for climate-related traits, to implement more efficient irrigation systems, to manage soil and water resources more efficiently, and to diversify their business enterprises rely to a greater or lesser degree on what is available from industry and government sources in the larger agri-food sector. Thus, even though the discussion in the foregoing focused on producer and farm level adaptation options, it implicitly recognizes the importance of developments in the broader industry and government programs.

5.2.4 THE ROLE OF THE STATE AND INDUSTRY IN CLIMATE CHANGE ADAPTATION

The agri-food sector is important for the Canadian economy and rural community viability. Consequently both federal and provincial levels of government are sensitive to climate and weather related risks and opportunities for agriculture. Crosson (1989) notes that once the social costs of climate change (both "priced" *i.e.* value of crops and livestock, and "unpriced", *e.g.* environmental costs) are felt, governments will feel compelled to address policy questions relevant for adaptation. Policy representatives from federal and provincial agricultural ministries acknowledge the value in understanding producers' needs and expectations to help with integrating climate change adaptation in policy (C-CIARN Agriculture, 2004).

Despite the diversity in regional conditions and production focus, there are similarities in how agricultural producers view federal and provincial climate change adaptation policy (C-CIARN Agriculture, 2004). These are summarized in Table 4, where seven challenges and their implications for policy and program development are noted. Producers representing various regions and commodity sectors raised these points during C-CIARN Agriculture's 2004 meeting in Gatineau, Quebec. Based on their discussion, it is evident that uncertainty and variability in all aspects of agricultural production present major risks that must be managed concurrently. Some producers want more government involvement, others want less. All want stability - whether it is the stability of an insurance program, or the stability of a not-rapidly-changing policy environment. At the same time flexibility in policies and programs is crucial to ensure diverse needs are met from conditions in various types of commodity production, farming systems, biophysical environments, and personal circumstances.

Another dominant theme from the C-CIARN Agriculture meeting (2004) is that climate risk is not managed in isolation of other risks, thus climate risk policy must not be developed in isolation from other government initiatives affecting the Canadian agri-food sector. Much work is needed to understand agricultural production from an operating farm perspective or "real farm experience" so that practical expectations can inform policy and programs and contribute to useful assessments of barriers and opportunities.

Table 4: Summary of risk management policy challenges, solutions, and recommendations relevant for climate change as identified by producers during C-CIARN Agriculture's 2004 meeting in Gatineau, Quebec

Challenge	Specifics	Solution	Recommendation for Policy
Economic Variability	Variation in: • income • interest rates • energy costs • dollar value	Income stabilization	• Main goal for agricultural policy should be agri-food sector stability • AAFC and provincial Ministries of Agriculture should ensure the outcomes for the agri-food sector are considered when other ministries develop policy and programs that affect it. • Income stabilization programs must be adequate for future climate and weather risks.
Sector Variability	Variation in conditions and requirements: • across commodities • across regions • across types of farming systems	A "one size fits all" solution is not possible. Flexible policies/programs that lead to equitable results.	• Ensure the diversity of conditions, needs and expectations for all sectors/regions are taken into account in policy and program development.
Mainstreaming	Adaptation to climate risks must be considered in light of other business risk strategies. Farming systems management is highly integrated.	Identify opportunities for integration into existing strategies. Identify potential barriers to integration and uptake. Become aware of real farm experiences.	• Substantial support for research is needed; it must feature a producer perspective and "whole farm context". • Research must include assessments of barriers to adaptation including policy/ program environment. • Include climate change adaptation in the APF; belongs directly in Business Risk Management but also relevant for other "pillars" (Environment, Food Safety, Innovation, and Renewal).
Barriers to adaptation	Some adaptation options for climate risk pose challenges for farming community: • additional costs to producers • GE solutions compromise marketing products • conflicts with existing policy	Research needed to identify: • adaptation costs/benefits • implications of GE technology • potential conflicts and ways to make them complementary	Support research that will: • provide long term and in-depth assessments • assess costs and benefits of climate risk adaptation options • Develop policy and programs based on research findings.

Challenge	Specifics	Solution	Recommendation for Policy
Adequate support	Some options require improved resources: • technology is lagging (*e.g.* weather forecasting needs to be more reliable) • knowledge transfer and financial support (incentives) needed to encourage effective risk management	Improved product development for "technological" adaptation options (*e.g.* weather and climate forecasting). View farm management practices in light of climate adaptation options.	• Re-establish research and extension services that work directly with producers • Establish climate change adaptation on "on-farm" demonstration sites.
Communication	Information about climate change risks is not always consistent or reliable. Insights from producers are not always recognized.	Improved resources for generating information. Enhanced "extension" services. Place more value on producers' knowledge.	• Ensure information from government is well supported through research and presented in useful formats. • Require producer representation on research and policy development teams.
Enhancing capacity	Farming community needs more capacity to manage risks. Public image of agri-food sector can be one of "neediness".	Look at past examples that worked (e.g. need for new grape varieties resulted in successful collaboration between industry and government) Initiatives that reward sound management.	• Work collaboratively with producers to ensure relevance of potential solutions. • Aim for policy environment that provides assistance while promoting producers' independence.

Examples of potential problems for producers managing climate risk include uncertainty in the value of climate data; apprehension about the public acceptance of recommended technology (e.g. GMOs); and potential conflicts among programs and policies. Research support, effective technology transfer and more collaboration among different government departments and ministries (as well as across federal, provincial and, in some cases local, lines) will go a long way in helping to generate policies and programs conducive for climate adaptation in the agri-food sector.

There are several ways that governments (often in partnership with the larger agri-food industry) can provide support for climate and weather risk management, including: sponsoring programs and subsidies for action; providing information for climate and weather impact reduction; supporting research programs; and ensuring crop insurance and income stabilization are effective.

5.2.4.1 Programs and subsidies

There is little or no research examining whether specific programs and their related incentives are useful for climate change adaptation in Canadian agriculture. In the U.S. however, such studies have been undertaken. Lewandrowski and Brazee (1993) argue that U.S. farm policy works against producers' ability to adopt management practices (for example, switching crops and investing in water conserving technologies) that constitute climate change adaptation. Leary (1999) investigates the cost-benefit issues related to climate change adaptation in the U.S. and points out the high degree of uncertainty surrounding benefits of adaptation. His recommendation is to delay implementing actions and programs that reflect only future climate concerns and focus instead on policy that generates benefits for current conditions (as long as they will also reduce vulnerability to future changes), which is now a widely promoted strategy in many areas. For example, Lewandrowski and Schimmelpfennig (1999) recommend that governments modify current farm programs regarding water conservation and restructure crop insurance and disaster relief to reflect added stress from altered weather and climate conditions.

Representatives of the Canadian agri-food sector agree that climate change adaptation strategy is an implicit element in many existing programs. For instance in Atlantic Canada, efforts exist now to introduce techniques that will aid potato farmers in dealing with climate and weather risks. Better crop rotation and strip cropping, the use of winter cover crops and green manures, conservation tillage, residue management, and mulching have been encouraged. On steeper fields, the strategies include contour and cross-slope cropping, the construction of diversion terraces and grassed waterways, enhancing land drainage and nutrient management, and introducing sediment control basins. By dealing with generic problems from runoff and erosion, many climate and weather risks are also addressed (Fairchild, 2004).

Many government programs for the agri-food sector are administered in partnership with established agricultural organizations, of which a large number exists in Canada. Among them are commodity groups, federations, and associations devoted to specific concerns such as soil and water conservation. Collaboration from such groups on a variety of government programs encourages participation from their membership. Integrating climate change adaptation into existing government/industry sustainability initiatives is a widely supported tactic (C-CIARN Agriculture 2004; Delaney *et al,* 2004; Tyrchniewicz and Yusishen, 2000; Wall and Smit, 2004). However, Lee *et al.* (1999) note the importance of evaluating farm level adaptation options within the larger environmental context. In their analysis of the U.S. corn belt, they investigate the effects of winter cropping to reduce soil erosion. Despite the general benefit from such a practice, the authors note that it can be a negative factor in some areas (namely those where the winter crop depletes soil moisture and subsequently adds to wind erosion and decreased corn productivity).

Their findings support the view that government agencies need to consider all outcomes before implementing broad programs and policies that target specific production practices. Producers expressed similar concerns regarding some Canadian agri-food sector policies (C-CIARN Agriculture, 2003). In this case, concerns were expressed regarding the conflict between promoting shelterbelts and smaller field size with regulations covering pesticide use.

Canadian examples of programs related to production practices reducing climate and weather related risks at the farm level include promotion of conservation tillage systems, and various land and water resource management schemes. For instance several initiatives, including the National Soil and Water Conservation Program (NSWCP) and the Agricultural Environmental Stewardship Initiative (AESI) have led to improvements in soil and water quality in many Canadian agricultural regions.

Encouraging better land and water resource management (through conservation practices and groundwater protection) results in beneficial environmental conditions that also reduce negative impacts from climate related events such as flooding and drought conditions.

5.2.4.2 Information provision

Besides these government/industry programs, there are examples of information services that directly enhance producers' choices for adapting to climate and weather risks. For instance, the Prairie Farm Rehabilitation Administration (PFRA) provides information on drought conditions and practices to reduce their impact. A sample of the topics available appears in Table 5.

Some provinces provide climate and weather information to assist in farm management decisions such as planting time, spraying requirements, and projected harvest conditions. Much of the information is the form of data on agroclimatic conditions. Growers in **British Columbia** for instance have access to *farmwest.com*, a web site with regional data on growing degree days, evapotranspiration, and corn heat units. **Alberta** and the **Prairie provinces** have a rich set of weather and climate information for producers to use. Historical agroclimatic data are available as are resources such as Grasshopper forecast maps, current condition reports and supply forecasts, weekly winter water report, status of major water storage reservoirs and mountain snow conditions, and water supply outlooks. ACE (Agrometeorology Centre of Excellence) in **Manitoba** offers a wide variety of products including daily weather and disease information, regional weather data, and maps indicating corn heat units and growing degree days. **Ontario** producers have access to services from the OWN (Ontario Weather Network) where highly specific information regarding weather conditions at the field level is available to subscribers. BeetCast, for instance, is a disease-warning model that establishes a timed fungicide spraying program for *Cercospora* on Sugarbeets. Based on weather data, specifically leaf wetness and temperature, BeetCast provides information related to disease control. Similar programs for processing tomatoes (TOMCAST) and *fusarium* in wheat are also available.

Short-term decision-making for production practices related to weather conditions is clearly enhanced with the systems and programs described above. This stands in contrast to what is needed for longer-term decision-making where the probability of wet/dry years is the significant issue. Research, which is fundamental for providing information and other government/industry services, is discussed in the next sub-section.

5.2.4.3 Research programs

Another way government and the agricultural industry work together to enhance producers' ability to manage climate risks is through joint research programs. Research efforts designed to improve agricultural sustainability also have relevance for climate risk reduction and related adaptation options at the farm level. For instance, the Potato Research Centre in **Atlantic Canada** sponsors several projects aimed at reducing runoff and soil loss from high intensity rainstorms (which are likely to increase with climate change). Rees *et al.* (2002) and Chow *et al.* (1999 and 2000) document the effectiveness of hay mulching, different tillage systems, and grassed waterway systems respectively, on land and water resources.

Table 5: Sample topics from PFRA on-line materials

Crops
- Alternatives to summerfallow
- Cropping decisions are tough in a year of drought
- Drought increases erosion concerns
- How to fertilize in a dry year
- Emergency control of wind erosion
- Is wheat the best crop to grow in a dry year
- Producers pipe up about better watering system
- Strip farming for wind erosion control
- Suitable fallow management helps preserve crop residue
- Trapping snow can increase yields

Livestock
- Securing livestock water during drought
- Shallow buried pipelines for summer pasture livestock watering
- Using cereals for feed during a drought

Pasture
- Community pastures
- Rangeland management during drought

Water
- Watch for sulphates and blue-green algae in cattle water supplies
- Farm water conservation during times of drought
- Farmers urged to choose water carefully
- Dugouts showing effects of drought
- Spring development
- Snow fences: there's water in that wind
- Water wells during drought
- Wells for rural water supplies in Saskatchewan

In the **Prairies**, crop diversification and irrigation research is supported through federal and provincial governments with the aim of improving agricultural sustainability in the region. An example is work completed at the Canada-Saskatchewan Irrigation Diversification Centre (CSIRDC). This facility has sponsored at least 26 research projects and 106 field scale demonstrations that have both direct and indirect implications for climate change (CSIRDC, 2000). Hogg *et al.* (1997), for example, examine the potential for using wastewater as an alternative source for irrigation systems. They conclude that the practice is acceptable as long as management practices are in place to offset potential problems with toxic compounds, infectious microorganisms, and salinity levels.

Results from several CSIRDC projects involving specialty horticultural crops and field crops shed light on the feasibility of adaptation options for altered climate and weather conditions. For instance, Hogg and MacDonald (2001) examine diversification issues in their work evaluating different pulse varieties to include in crop rotation. Likewise Zentner *et al.* (2001) at the Semiarid Prairie Agriculture

Research Centre find that practices such as reducing summerfallow and adopting rotations of pulse crops and wheat for farms in semi-arid regions of Canada have both economic and environmental benefits. Findings such as this are relevant for adaptation options in projected climate conditions where an increase in dry conditions is anticipated.

Since 1978, the **Alberta** Agricultural Research Institute has sponsored over one hundred research projects with relevance for drought conditions, primarily as on-farm demonstration projects. Similar examples of government and industry collaboration in research can be found in all Canadian provinces. Many research projects focus on improving technology so that agricultural production can be more efficient in light of increasing climate and weather risks. For instance, minimizing water use through highly efficient irrigation systems continues to be a major concern for researchers and producers in the Okanagan Valley, **British Columbia.** Projects out of PARC (Pacific Agriculture Research Centre) include developing irrigation systems to deliver water precisely when orchards need it (AAFC, 2002).

Another example of technological developments for adaptation to altered climate and weather conditions is crop breeding. However, there is little evidence that crop developers emphasize 'robustness' to climatic variations (also known as stability and resilience) in their programs (Rosenberg, 1981; Smithers and Blay-Palmer, 2001). It has been suggested (Tollenaar *et al.*, 1994; Tollenaar and Wu 1999), that in the case of corn, such improvements might have been an "accidental" outcome related to the nature of breeding selection. On the other hand, van Herk (2001) notes that not only is climatic variability not a target for crop breeding (although it could be), but also that an anomalous climatic season is seen as an inconvenience in field testing, with its results discarded, rather than an opportunity to test for and retain the robustness features of the crop variety.

Recent crop development research is increasingly using biotechnological solutions, that is, genetically modified organisms are introduced into plant products. Without defining biotechnology, Evenson (1999) uses the IFPRI-IMPACT model (IFPRI stands for International Food Policy Research Institute; IMPACT refers to the International Model for Policy Analysis of Agricultural Commodities) to support his claim that without incorporating genetic engineering into adaptation options, climate change will result in substantial crop losses and subsequent local food crises in the developing world. Agribusinesses (for example Performance Plants in Kingston, Ontario) are using genetic technology and starting to develop high-yielding drought-tolerant varieties of many crop species commercially available. Countries such as Mexico are testing genetically modified, drought tolerant wheat in experimental plots (CIMMYT, 2004).

Food safety aspects of biotechnologically developed products are a major concern for some scientists (for example see Cummins (2004) regarding potential problems with transgenic drought tolerant rice.) As well, experience with marketing challenges related to the use of biotechnological solutions makes some producers very cautious about proceeding in that vein and points to the need for extensive research before proceeding too far (Garr, 2004). Easterling *et al* (2004:20) concur, noting: "Social acceptability of technology given real or perceived risks can be a significant barrier to technological adoption and diffusion."

5.2.4.4 Crop insurance and income stabilization

Uncertainty is a major feature for farming enterprises with variability in climate and weather conditions compounding the instability in macroeconomic, biophysical, technological, and policy environments (Wandel and Smit, 2000). One of the main strategies producers employ to transfer risk from uncertain outcomes in the environment and economic realms is to purchase crop insurance. The aim is to pass the risk of yield loss, and therefore income loss, to a third party before or during exposure to risk. Federal and provincial governments play an important role in developing and supporting crop insurance schemes and have been involved with them for several decades (Asselstine, 2003). Livestock insurance is also available but, for a variety of reasons, livestock plans are not as well developed as those for crops.

National crop insurance statistics indicate an increase in use of existing programs. Statistics Canada (2003) reports that the dramatic increase in producers' receipts from program payments in the first six months of 2003 (79.2 per cent increase from the same period of 2002 and almost double the previous five-year average) is largely a result of record payments through crop insurance programs following two consecutive years of drought for Prairie producers.

Saskatchewan alone paid $825 million dollars for 2002 crop losses, a figure more than double the amount needed for the 1988 drought. Analysts also claim that Saskatchewan's current deficit is largely attributable to the economic costs of recent droughts (*Globe and Mail,* July 22/03) Alberta has spent more than $1.8 billion on *ad hoc* drought relief since 1984 (SSCAF, 2003). Ontario crop insurance payments are also cause for concern. Analysis has shown that from 1966-2000, payments for insured crops totaled approximately $1 billion while those from 2000-2004, are roughly $640 million (Cudmore, 2004).

Given their escalating importance to the agri-food sector, crop insurance issues are well researched in the agricultural economics and policy literature. Because insurance claims are linked to yield loss and yield is closely tied to climate and weather conditions, most crop insurance studies have some degree of relevance for climate and weather risk transfer. Some however, examine crop insurance issues specifically in light of changing climate and weather conditions. Turvey (2001), for instance, finds that rather than insuring against crop damage related to weather impacts, it is more effective to insure against the cause of the damage itself (*i.e.* the climate or weather event such as drought, hail, extreme heat). Interest is increasing in using these weather derivatives because they can be used to cover low risk, high probability events as opposed to most insurance products which cover high risk, low probability events such as floods or fire (Chance, 2003). Because pay outs are based on objective weather data, the need for insurance adjusters to assess crop damage becomes unnecessary, thereby reducing costs and subjectivity. In Alberta however, there is evidence that the system might be problematic. Farmers in some regions claim moisture data used by the Alberta Financial Services Corporation include inaccurate figures which suggest that moisture was above normal levels even though their fields are drier and more grasshopper-infested than ever before (CBC News, Aug. 31/03).

Mahul and Vermersch (2000) analyze the problem of hedging crop risk against crop yield insurance futures and options rather than weather derivatives. They conclude that catastrophic weather events have become the major factor in yield variability and therefore crop insurance pay outs. Ker and McGowan (2000) investigate implications of "weather-based adverse selection" in the United States. Adverse selection occurs when growers of different loss-risk are charged premiums that do not reflect this difference. As a result, only those taking on high risks buy insurance and the insurer becomes more likely to incur actuarial losses. Adverse selection generally exists whenever the insured person has better knowledge of the relative riskiness of a particular situation than the insurance provider does.

Ker and McGowan (2000) also note that farmers in the U.S. tend not to include weather-based information in their decisions for purchasing insurance but private insurance companies do (in pursuit of re-insurance) and subsequently benefit from government compensation under current reinsurance agreements. Farmers use of crop insurance in Canada has some similarities to that in the United States. Smithers and Smit (1997) suggest that crop insurance programs appear to reduce sensitivity of producers to unfavourable years, that is they farm the insurance program knowing they will get some income. In general, there may be less incentive to adopt individual risk management strategies if governments serve that purpose (Lewandrowski and Brazee, 1993; Smit *et al.,* 2000).

Additional strategies for managing climate and weather risks include income stabilization programs and disaster relief. The future of such programs in Canada is negotiated between federal and provincial governments. The Business Risk Management section of Agricultural Policy Framework (APF) now provides compensation for unfavourable consequences from climate and weather conditions by integrating across existing programs for income stabilization and disaster relief. Policy makers and producers alike recognize the need to integrate other climate related adaptation strategies into additional "pillars" of the APF (namely food safety, innovation, environment, and renewal) (C-CIARN Agriculture, 2004).

Discussion in the foregoing section focuses on climate risk management and related adaptation options. Issues, and therefore related research, are wide-ranging. They often link to data and information gathered for other topics of concern, further supporting the fact that climate and weather risk management cannot be understood as an isolated component for farm decision-making, policy development, and research endeavour.

A number of points are supported with the literature and research reviewed for this section on climate risk management and adaptation opportunities. For instance, it appears that a great deal is unknown about how producers perceive climate risk and make decisions regarding adaptation strategies; they tend not to identify climate and weather as "risks" even though they incorporate such considerations into decision-making. As well, there is much to learn about existing programs and policies and how they are relevant for adaptation strategies; little has been done to identify commonalities and potential conflicts.

6. VULNERABILITY AND ADAPTIVE CAPACITY

Sections 4 and 5 of this position paper contain summaries of climate change adaptation literature and information from two different perspectives. The first, "scenario-based assessments", constitutes the main body of work on the topic of agricultural adaptation to climate change. The second, "climate risk management and adaptation options", has fewer research results to draw on but includes material that is relevant for climate change adaptation even though it has been written with other themes in mind. In this section the discussion turns to an approach focusing on vulnerability and adaptive capacity. The "vulnerability approach" brings with it possibilities for gaining new insights into climate change adaptation processes, barriers, and opportunities relevant for Canadian agriculture.

Vulnerability refers to the likelihood that a given system will be harmed by exposure to hazard (Polsky *et al.*, 2003; Turner *et al.*, 2003). The IPCC identifies that vulnerability to climate change is a function not only of the system's sensitivity but its ability to adapt to new climatic conditions (IPCC, 2001). Sensitivity, in this case, refers to how a system will respond to a climate stimulus whereas adaptability is how well the system adjusts to this response. For example, a crop-based agricultural system that is exposed to drought (the hazard) will experience yield declines (sensitivity) which may have various effects on the region based on responses such as irrigation use, crop insurance, the availability of less moisture-reliant cultivars and the farmer's management ability (adaptability). Thus, a modest change in climate may have little direct effect on a system that is not highly sensitive to the hazard (*e.g.* feedlot operations who do not grow their own feed) or a system that is highly adaptable (*e.g.* farmers carrying sufficient crop insurance or with irrigation capacity). The same change, however, may have a large effect on a system that has both high sensitivity and low adaptability (*e.g.* a cash crop operator without access to irrigation who is not carrying crop insurance). Generally, vulnerability increases with sensitivity and decreases with adaptive capacity, which is defined for climate change as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. (McCarthy *et al.*, 2001).

Research that considers the time and place specific nature of the potential or likelihood of a system to experience harm from a climate event is collectively referred to as taking the "vulnerability perspective" (Polsky *et al.*, 2003). While vulnerability scholarship as yet is not as well developed as either work on mitigation or scenario-approaches for impacts and adaptation (Clark *et al.*, 2000; Polsky *et al.*, 2003), leading non-governmental organizations such as the IPCC, the World Economic Forum and the World Food Programme have adopted a vulnerability perspective (Clark *et al.*, 2000).

Polsky *et al.* (2003) note that the ideas captured in vulnerability assessment are not new, and trace the perspective to previous work in natural hazards assessment, risk management and food security. The application of a vulnerability perspective to climate change impacts and adaptation research is still in its infancy and has the following characteristics:

- It considers a variety of stresses, both climatic and non-climatic.
- It considers not just the "what?" (the hazard) but the "on what?" (the conditions of the system exposed to the hazard).
- It is time and place specific, but with a recognition of what came before and the larger environment within which a place exists .
- It involves stakeholders.
- It takes an "inverse" approach, which starts with the system (farm/community/sector/region) under consideration rather than a particular hazard.

As the previous sections of this paper identified, farmers manage various risks on a daily basis. Weather and climate are considered in conjunction with commodity prices and other considerations to arrive at farm business decisions. It is thus not surprising that farmers frequently raise non-climate concerns (e.g. issues surrounding the Pesticide Management Regulatory Agency) even in climate-change specific discussions of their adaptation strategies (C-CIARN Agriculture 2004). Producers do not use one suite of risk management strategies for climate, another for price risk, another for health and safety concerns, and so forth. Rather, effective farm management includes all sources of risks (and opportunities) in the decision-making process (Bryant *et al*., 2004). Also important are a number of factors in the wider environment. Tan and Reynolds (2003) point out that future demands for water resources will be affected by surrounding land quality (i.e. prevalence of pasture, woodlots, and wetlands) as well as water demands from an increasing population and industry. Turner *et al.* (2003) and Polsky *et al.* (2003) refer to this as the "coupled human-environment system" to highlight that the human (farmer decision-making, institutional parameters, etc.) and environmental (climate conditions, soil constraints, biophysical production, etc.) are part of an integrated whole.

Implicit in the vulnerability perspective is the time and place specific nature of assessment (the multiple risks and opportunities, and the situational and historical context within which these operate). Such information is impossible to capture without the inclusion of stakeholders at every stage of the assessment. Thus the vulnerability approach is distinctive in climate change adaptation research because it requires that producers and others in the agri-food sector (eg. industry representatives and policy makers) work together with researchers to design and carry out specific adaptation projects.

6.1 CONDUCTING RESEARCH EMPLOYING THE VULNERABILITY APPROACH

Research issues related to the vulnerability approach primarily focus on past conditions and may incorporate projections to future conditions. Details of the research issues and objectives related to climate change vulnerability assessments are summarized in Table 6.

The research objectives described in Table 6 under current and future conditions are purposefully non-specific regarding type of stress or opportunity. As noted, vulnerability assessments for agriculture require understanding climate and weather risks in the context of other challenges and opportunities. To do so acknowledges the multi-faceted nature of risk management on the farm. The agri-food sector's capacity to meet challenges and take advantage of opportunities related to climate change depends directly on a number of other conditions. For instance, decisions regarding diversifying crops are based on climate/growing conditions in light of the potential market, environmental conditions, technological requirements, human resources, and so on.

Table 6. Research Issues and Objectives for Vulnerability Assessments

Theme	**Research Objective**
Current Conditions	Identify conditions that are beneficial and/or problematic to the system under investigation.
Current Capacity	Assess how successful management strategies are for adapting to stress and/or opportunities. Determine effectiveness of policy and programs in assisting producers with their adaptation measures.
Future Conditions	Assess the likelihood that there will be changes in the trends and magnitude of beneficial and/or problematic conditions.
Future Capacity	Assess adaptive capacity to meet future risks and opportunities. Assess the suitability and viability of current policy and programs to meet future requirements.

Once current vulnerabilities are established, it becomes possible to identify climate conditions which are relevant for the system under consideration. Vulnerability research can thus include specific climate scenarios to identify future potentially problematic conditions. These projections can be coupled with an assessment of future adaptive capacity (based on stakeholder input and anticipated changes in the relevant socio-economic-policy environment) to arrive at an estimation of "future adaptive capacity". Future exposure and adaptive capacity together allow for predictions of future vulnerability (see Figure 3).

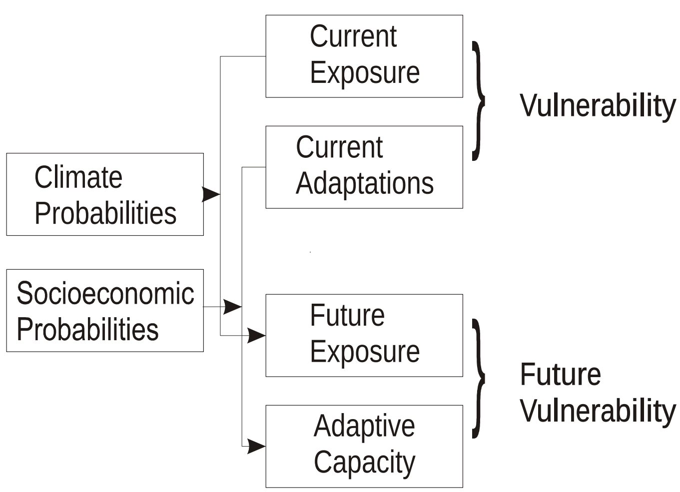

Figure 3: A Conceptual Framework of Vulnerability (Smit, 2003)

6.3 VULNERABILITY RESEARCH IN CANADA

Researchers are just beginning to conduct climate change vulnerability assessments for specific types of Canadian farming systems. One example is the work of Reid (2003), whose study of producers in Perth County, Ontario examines farm-level perception of, and responses to, climate variability and change. She documents producers' views on beneficial and problematic conditions for their operations and notes they vary from year to year. Included in producers' assessments of the important factors are: climate, economic and market conditions, technology, environment (soil, water, pests), government programs and policies, and farm/family attributes.

Reid also provides extensive accounts of how individual producers continue to adapt to specific climate and weather conditions encountered in current operating years, noting the positive as well as negative outcomes (see Appendix "C" for Tables based on Reid 2003:Tables 12 A and B).

Similar research is on-going in prairie and western regions of Canada. Early findings from Ramsey and Tarleton (2004) provide a substantial list of practices that Manitoba farmers identify as useful for managing climate and weather risks. (see Appendix "D" for Tables based on Ramsey and Tarleton, 2004).

A review of the responses in both Ontario and Manitoba research confirms a number of important points that the vulnerability approach brings to agricultural climate change adaptation studies:

- Producers have valuable information to contribute; they must be included in climate risk management and adaptation research.
- Diversity in regional conditions and demands from specific commodity production make generalization difficult.
- Weather and climate risk management are integrated into existing production practices and farm financial management.
- Producers are actively engaged in adapting to climate and weather risks even if they do not use that language to describe their actions.

Results from Reid (2003) and Ramsey and Tarletone (2004) work constitute the first stage of a vulnerability assessment for Canadian agriculture by documenting exposure to relevant hazards for existing farming systems. A small number of Canadian scholars are currently involved in similar pursuits with research results pending. Output from their studies can feed into assessments of producers' capacity for dealing with the conditions identified and then be coupled to work on future exposure and adaptive capacities.

Pursuing the vulnerability perspective requires closer integration of researchers from the social sciences with climate modelers and natural scientists. In scenario-based research, work begins with modeling and the role of human agency is only considered after future climate and impacts have been predicted. Research which employs the vulnerability perspective incorporates human agency at the outset, and what is relevant and potentially problematic for farmers and their capacity to deal with stresses is a key input into modeling exercises. Thus research into producer perspectives and actions (traditionally done by social scientists) receives earlier and more prominent consideration than it does in scenario-based approaches. Empirical work which incorporates human agents is both time and cost-intensive. This may partially explain why financial and human resources supporting vulnerability have so far been limited. However, as the need for climate change planning and policy increases, so too does the need for the type of data and information that come from research focused on vulnerability and adaptive capacity.

7. CONCLUSIONS: RESEARCH GAPS AND RECOMMENDATIONS

This position paper reviews the current state of knowledge about climate change risks and opportunities for the Canadian agri-food sector. The discussion is organized around three distinct but related topics, namely: scenario-based impact assessments; climate risk management and adaptation opportunities; and vulnerability and adaptive capacity. Based on the information presented, a number of gaps can be identified for research approach and support and government policy. These are presented below along with specific recommendations for addressing them.

Research Approach and Support

Responses from industry and policy representatives suggest results from climate scenario/model approaches are limited. There is merit in adopting a research perspective that meets the following criteria: is rooted in what is "known" and accommodates diversity; incorporates producer based experience and knowledge; encourages integration; and builds on existing capacity. These features form the basis for a research perspective known as the vulnerability approach.

Recommendation: Employ the vulnerability approach for climate change adaptation research.

- ***Enhance knowledge of producer' experiences with climate and weather risks and how these affect adaptation choices.***
- ***Incorporate knowledge of farm production practices and management so that linkages to existing (and future) programs and policies can be identified and acted on.***
- ***Ensure that climate scenarios and related models include agro-climatic conditions identified as relevant by the agri-food sector.***
- ***Encourage climate change related research projects to incorporate whole farm perspectives.***

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Research that increases certainty in predictive climate models does not necessarily serve producers' needs. They know certainty is elusive and ask for research-supported information about managing uncertainty.

Recommendation: Support research that enhances the adaptive capacity of Canadian agriculture and results in reliable products for managing climate risk and uncertainty.

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Government Policy

Climate and weather conditions are among the most significant factors affecting production outcomes for Canadian agriculture and may exert increasing pressure on crop insurance and income stabilization. However, it appears that climate risk management is not directly addressed in the Agricultural Policy Framework, nor in other programs where it has relevance.

Recommendation: Assess the current and any future versions of the Agricultural Policy Framework (APF) in light of agri-food sector requirements for climate change adaptation.

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Climate and weather information services are crucial for making short term production decisions, for example determining when to use chemical sprays in horticultural production. Improved availability of systems based on this information will enhance producers' ability to manage climate and weather related risks.

Recommendation: Improve existing climate and weather data collection and services related to them.

***

Greenhouse gas mitigation studies dominate the climate change research agenda despite Canadian commitment to pursue a number of adaptation related initiatives, including, raising awareness of adaptation; facilitating and strengthening capacity for coordinated action; incorporating adaptation into government planning processes; promoting and coordinating research on adaptation; supporting networks to share knowledge; and providing methods for adaptation planning.

Recommendation: Make climate change adaptation related research a funding priority.

***

Directing research efforts more effectively while enhancing support lies at the heart of addressing the gaps and fulfilling the recommendations put forth here. But perspectives that are sensitive to the requests from producers and policy-makers alike must inform that research if there is to be effective climate change adaptation in the Canadian agri-food sector. The vulnerability approach with a focus on adaptive capacity is one perspective that offers such promise. It has the potential to meet several of the needs and expectations for both research and policy development related to climate and weather risks. While changing research paradigms is a daunting challenge, it can be done. Producers themselves demonstrate the value of altering management strategies, taking risks, and trying new methods. The time is right for agri-food researchers and policy makers interested in climate change adaptation to follow their example.

REFERENCES

Adams, R., B. Hurd, S. Lenhart, N. Leary.1998. Effects of global climate change on agriculture: an interpretive review. *Climate Research,* 11:19-30.

Adams, R. B. McCarl, and L. Mearns. 2003. The Effects of Spatial Scale of Climate Scenarios on Economic Assessments: As example from U.S. Agriculture. *Climate Change,* 60:131-148.

Adger, W.N. and P.M. Kelly, 1999. Social Vulnerability to Climate Change and the Architecture of Entitlements. *Mitigation and Adaptation Strategies for Global Change*, 4(3/4): 253-266.

AAFC (Agriculture and Agri-food Canada). 2002. Irrigation System operates on a 'Need to Drink' Basis. *Agvance*, 9(3):4.

AAFC (Agriculture and Agri-food Canada). 2003a. "The Promise and Pitfalls of Diversifying into New Crops". *Canadian Farm Manager,* October/November.

AAFC (Agriculture and Agri-food Canada). 2003b "Innovation in agriculture: finding the better way" *Canadian Farm Manager,* April/May.

Andresen, J., G. Alagarswamy, D. Stead, H. Cheng, and B. Sea. 2000. *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change in the Great Lakes Region (Agriculture).* Great Lakes Regional Assessment. http://www.geo.msu.edu/glra/assessment/assessment.html

André, P. and C. Bryant. 2001. *Les producteurs agricoles face aux changements climatiques: une évaluation des strategies d'investissement des producteurs de la Montérégie-ouest (Québec).* Rapport de recherché pour le Fonds D'action sur les changements climatiques du Canada.

Antle, J. 1996. Methodological issues in addressing potential impact of climate change on agriculture. *Agriculture and Forest Meteorology*, 80: 67-85.

Antle, J.M., S.M. Capalbo, and J. Hewitt. 2004. Adaptation, Spatial Heterogeneity, and the Vulnerability of Agricultural Systems to Climate Change and CO2 Fertilization: An Integrated Assessment Approach. *Climatic Change,* 64(3):289-315.

Archambault, D.J.; Li, X.; Robinson, D.; O'Donovan, J.T.; Klein, K.K. 2001. *The Effects of elevated CO2 and temperature on herbicide efficacy and weed/crop competition*. Report prepared for the Prairie Adaptation Research Collaborative (PARC).

Arthur, L. and F. Abizadeh. 1988. Potential effects of climate change on agriculture in the Prairie region of Canada. *Western Journal of Agricultural Economics*, 13: 216-224.

Arthur, L.M. and G.C. Van Kooten. 1992. Climate impacts on the agribusiness sectors of a prairie economy. *Prairie Forum,* 17: 97-109.

Asselstine Alan, 2002. Canada's Crop Insurance and Disaster Assistance Programs. Presentation for Australian Agricultural and Resource Economics Society Pre-Conference Workshop, Managing Climate Risks in Agriculture. Ferndale, Western Australia, February.

Aubin, P. G. Auger, and C. Perreault. 2003. *Climate Change and Greenhouse Gas Awareness Study Report.* Agriculture and Agri-food Canada. http://www.c-ciarn.uoguelph.ca/documents/clima_e.pdf

Baker, B.B., J.D. Hanson, R.M. Bourdon and J.B. Eckert. 1993. The potential effects of climate change on ecosystem processes and cattle production on U.S. rangelands. *Climatic Change,* 25(2): 97-117.

Bélanger, Gilles, Philippe Rochette, Yves Castonguay, Andrew Bootsma, Danielle Mongrain, and Daniel A. J. Ryan. 2002. Climate change and winter survival of perennial forage crops in Eastern Canada. *Agronomy Journal*, 94(5): 1120-1130.

Benioff, F., S. Guill, and J. Lee (eds.). 1996. *Vulnerability and Adaptation Assessments: An International Handbook*. Dordrecht: Kluwer Academic Publishers.

Blasing, T.J. and A.M. Solomon. 1984. Response of the North American Corn Belt to climate warming. *Progress in Biometeorology,* 3: 311-321.

Boland, G. , V. Higgins, A. Hopkin, A. Nasuth, and M. Melzer. 2003. Climate change and plant disease in Ontario. In S. Griefenhagen and T. Noland (eds), *A Synopsis of the Known and Potential Diseases and Parasites Associated with Climate Change*. Forest Research Information Paper No. 154: 7-89. Ontario Ministry of Natural Resources.

Bootsma, A., S. Gameda, D. McKenny, P. Schut, H. Hayhoe, R. de Jong, E. Huffman. 2001. *Adaptation of Agricultural Production to Climate Change in Atlantic Canada*. Final Report submitted to the Climate Change Action Fund.

Bootsma, A., D. Anderson and S. Gameda. 2004. *Potential Impacts of Climate Change on Agroclimatic Indices in Southern Regions of Ontario and Quebec*. ECORC Contribution No. 03-284. Eastern Cereal and Oilseed Research Centre, Research Branch, Agriculture and Agri-Food Canada.

Bradshaw, B. and H. Dolan. 2001. Crop Diversification as an Adaptive Response to Climate and other Risks in the Prairies. Presentation for the Annual Meeting of the Canadian Association of Geographers, Montreal, Quebec.

Brklacich, M. and B. Smit. 1992. Implications of changes in climatic averages and variability on food production opportunities in Ontario, Canada. *Climatic Change,* 20: 1-21.

Brklacich, M. and R.B. Stewart. 1995. Impacts of climate change on wheat yields in the Canadian Prairies. In C Rosenzweig (ed.), *Climate Change and Agriculture: Analysis of Potential International Impacts*. Madison, Wisconsin: Special Publication No. 59, American Society of Agronomy, 147-162.

Brklacich, M., C. Bryant, B. Veenhof, and A, Beauchesne. 1998. Implications of global climatic change for Canadian agriculture: a review and appraisal of research from 1984 to 1997. In G. Koshida and W. Avis (eds.), *Canada Country Study, Volume 1: Synthesis and Research Needs.* Government of Canada.

Brklacich, M., D. McNabb, C. Bryant and J. Dumanski, 1997. Adaptability of agricultural systems to global climate change: a Renfrew County, Ontario, Canada pilot study. In B. Ilbery, Q. Chiotti and T. Rickard (eds.), *Agricultural Restructuring and Sustainability: A geographical perspective.* Wallingford: CAB International, 351-364.

Bryant, C R, P. Andre, J-P. Thouez, B. Singh, S. Frej, D. Granjon, J-P. Brassard, and G. Beaulac. 2004. Agricultural adaptation to climate change: the incidental consequences of managing risk. In D. Ramsey and C. Bryant (eds), *The Structure and Dynamics of Rural Territories: Geographical Perspectives.* Brandon: Rural Development Institute, Brandon University.

Bryant, C.R. and P. André. 2003. Adaptation and sustainable development of the rural community, Laurens, L. and Bryant, C.R. (eds.), *La Durabilité des Systèmes Ruraux, une Construction Sociale et Culturelle / The Sustainability of Rural Systems - A Social and Cultural Construction.* Actes du Colloque Annuel 2001 de la Commission de l'UGI sur le Développement Durable des Systèmes Ruraux. Montréal and Montpellier : IGU Commission on the Sustainability of Rural Systems and the Université Paul Valéry, 449-460 in

Bryant C.R., B. Smit, M. Brklacich, T.R. Johnston, J. Smithers, Q. Chiotti, and B. Singh. 2000. Adaptation in Canadian agriculture to climatic variability and change. *Climatic Change,* 45: 181-201.

Burton, I. 1997. Vulnerability and adaptive response in the context of climate and climate change. *Climatic Change,* 36: 185-196.

Burton, I., S. Huq, B. Lim, O. Pilifosova, E.L. Schipper. 2002. From impacts assessment to adaptation priorities: the shaping of adaptation policy. *Climate Policy,* 2: 145-159.

CIMMYT (International Wheat and Maize Improvement Center). 2004. In quest for drought-tolerant varieties, CIMMYT sows first transgenic wheat field trials in Mexico. News item on CIMMYT web site, http://www.cimmyt.org/english/webp/support/news/dreb.htm

C-CIARN Agriculture. 2002. Report from Producer Survey at Canada's Outdoor Farmshow, Woodstock, Ontario. September.

C-CIARN Agriculture. 2003. *Meeting the Challenges form Climate Change.* Summary report from C-CIARN agriculture Round Table, Grainworld, Winnipeg, Manitoba, February 25.

C-CIARN Agriculture. 2004. *Climate Change Adaptation-A producer Perspective on Policy and Programs.* Report on C-CIARN Agriculture Meeting, Gatineau Quebec, February 25.

CSIDC (Canada-Saskatchewan Irrigation Diversification Centre). 2000. Overview publication.

CSIDC (Canada-Saskatchewan Irrigation Diversification Centre). 2001. Annual review 2000-01.

Chakraborty, S., A.V. Tiedemann, and P.S. Teng. 2000. Climate change: potential impact on plant diseases. *Environmental Pollution*, 108 (3): 317-326.

Chance, K. 2003. Managing climate risk in agriculture. *Connections,* 5(3): 20-22.

Charron, D., D. Waltner-Toews, A. Maarouf, and M. Stalker. 2003. A synopsis of the known and potential diseases and parasites of humans and animals associated with climate change in Ontario. In S. Griefenhagen and T. Noland (eds), *A Synopsis of the Known and Potential Diseases and Parasites Associated with Climate Change*. Forest Research Information Paper No. 154: 7-89. Ontario Ministry of Natural Resources, 7-89.

Chiotti, Q. 1998. An assessment of the regional impacts and opportunities from climate change in Canada. *Canadian Geographer,* 42: 380-393.

Chiotti, Q.P., and T. Johnston. 1995. Extending the boundaries of climate change research: a discussion on agriculture. *Journal of Rural Studies,* 11: 335-350.

Chiotti, Q., T. Johnston, B. Smit, and B. Ebel. 1997. Agricultural response to climate change: a preliminary investigation of farm-level adaptation in Southern Alberta. In B Ilbery, Q. Chiotti, and T. Rickard (eds.), *Agricultural Restructuring and Sustainability.* Wallingford: CAB International, 201-218.

Chow, R., H. Rees, and J. Monteith. 2000. Seasonal distribution of runoff and soil loss under four tillage treatments in the upper St. John River valley, New Brunswick, Canada. *Canadian Journal of Soil Science,* 649-660.

Chow, R., H. Rees, and J.L Daigle. 1999. Effectiveness of terraces/grassed waterway systems for soil and water conservation: a field evaluation. *Journal of Soil and Water Conservation*, 54(3): 577-583.

Climate Change Connection. http://www.climatechangeconnection.org/pages/manitobans.html

Cloutis, E., A. Kirch, G. Wiseman, J. Golby, and D. Carter . 2001. .*Socio-Economic Vulnerability of Prairie Communities to Climate Changes.* PARC publication. http://www.parc.ca/publications.htm

Cline, W. 1992. *The Economics of Global Warming.* Washington D.C.: Institute for International Economics.

Coakley, S. 2004. Plant disease management. In D. Wolfe (ed.), *Proceedings: Impacts of Climate Change on Horticulture Symposium*; Nov 2, 2003, Providence, RI.

Coakley, S.M., H. Scherm, and S. Chakraborty. 1999. Climate change and plant disease management. *Annual Review of Phytopathology,* 37: 399-426.

Cohen, R.D.H., C.D. Sykes, E.E. Wheaton, and J.P. Stevens. 2002. *Evaluation of the Effects of Climate Change on Forage and Livestock Production and Assessment of Adaptation Strategies on the Canadian Prairies.* Report submitted to the Prairie Adaptation Research Collaborative (PARC).

Crosson, P. 1989. Climate change and mid-latitudes agriculture: perspectives on consequences and policy responses. *Climatic Change,* 15: 51-73.

Cudmore, P. 2004. Agricorp's Ontario Weather Data Collection Grid. Presentation at Long-Range Climate and Impacts Forecasting Working Group Meeting V, Ramada Inn, Guelph, Ontario. March 15-17.

Cummins, J. 2004. Making rice drought resistant by enhancing polyamines: poisonous seeds? Distributed via SANET, http://lists.ifas.ufl.edu/cgi-bin/wa.exe?A1=ind0408&L=sanet-mg#top

Curry, R.B., J.W. Jones, K.J. Boote, R.M. Peart, L.H. Allen, Jr,, and N.B. Pickering. 1995. Response of soybean to predicted climate change in the USA. . In: C. Rosenzweig (ed.), *Climate Change and Agriculture: Analysis of Potential International Impacts*. Madison, Wisoconsin: Special Publication No. 59, American Society of Agronomy, 163-182.

Darwin, R., M. Tsigas, J. Lewandrowski, and A. Raneses. 1995. *World Agriculture and Climate Change: Economic Adaptations*. Department of Agriculture, Washington, D.C.: U.S. Agricultural Economic Report N. 703.

de Jong, R., A. Bootsma, T. Huffman, and G. Roloff. 1999. Crop Yield Variability under Climate Change and Adaptive Crop Management Scenarios. Final project report submitted to the Climate Change Action Fund.

Delaney, P., A. Kaul, and C. Miller. 2004. *Weathering Natural Disasters-Refocusing Relief and Development through Improved Agriculture and Environmental Practices*. Report for Future Harvets and CARE. http://www.futureharvest.org/pdf/Weathering_Nat_Disas.pdf

Delcourt, G. and G. C. van Kooten. 1995. How resilient is grain production to climatic change? Sustainable agriculture in a dryland cropping region of western Canada. *Journal of Sustainable Agriculture,* 5(3): 37-57.

DesJarlais, C., A. Bourque, R. Decoste, C. Demers, P. Deschamps, and K. Lam (eds.). 2004. *Adapting to Climate Change*. Report from Ouranos. http://www.ouranos.ca/cc/climang5.pdf

Easterling, W. 1996. Adapting North American agriculture to climate change in review. *Agricultural and Forest Meteorology*, 80: 1-54.

Easterling, W.E., N.J. Rosenberg, M.S. McKenney, K. Lemon, and M.S. McKenney.1992a. Simulations of crop responses to climate change: effects with present technology and currently available adjustments (the 'smart farmer' scenario). *Agricultural and Forest Meteorology*, 59: 75-102.

Easterling, W.E., N.J. Rosenberg, M.S. McKenney, C.A. Jones, P.T. Dyke, and J.R. Williams. 1992b. Preparing the Erosion Productivity Impact Calculator (EPIC) model to simulate crop response to climate change and the direct effects of CO "SUB 2". *Agricultural and Forest Meteorology*, 59: 17-34

Easterling, W.E., P.R. Crosson, N.J. Rosenberg, M.S. McKenney, L.A. Katz, and K.M. Lemon. 1993. Agricultural impacts of and responses to climate change in the Missouri-Iowa-Nebraska-Kansas (MINK) region. *Climatic Change,* 24: 23-61.

Easterling, W.E., C.J. Hays, M. McKenney-Easterling, and J.R. Brandle. 1997. Modelling the effect of shelterbelts on maize productivity under climate change: an application of the EPIC model. *Agriculture, Ecosystems and Environment*, 61(2-3): 163-176.

Easterling, W.E., B. Hurd, J. Smith. 2004. Coping with Global Climate Change: The Role of Adaptation in the United States. Prepared for the Pew Center on Global Climate Change. http://www.pewclimate.org/docUploads/Adaptation%2Epdf

El Maayar, M., B. Singh, P. Andre, C.R. Bryant, and J.P. Thouez. 1997. The effects of climatic change and CO_2 fertilization on agriculture in Quebec. *Agricultural and Forest Meteorology,* 85: 293-208.

Erith, D. 2003. Comments during Adaptation to Climate change: Key Issues for Agriculture*,* Climate Adaptation and Greenhouse Gas Mitigation in Agriculture Workshop. Nova Scotia Agricultural College, Truro, N.S., April 14.

European Commission. 2001. *Risk Management Tools for EU Agriculture*. Agriculture Directorate-General, http://europa.eu.int/comm/agriculture/publi/insurance/text_en.pdf

Evenson 1999. Global and local implications of biotechnology and climate change for future food supplies.

Fairchild, G. 2004. Agriculture in Atlantic Canada. Presentation at Climate Change Adaptation - A Producer Perspective on Policy and Programs. C-CIARN Agriculture meeting, Gatineau Quebec, February 25.

Fischer, G., K. Frohberg, M.L. Parry, and C. Rosenzweig. 1995. Climate change and world food supply, demand, and trade. In C. Rosenzweig (ed.), *Climate Change and Agriculture: Analysis of Potential International Impacts*. Madison, Wisconsin: Special Publication No. 59, American Society of Agronomy, 341-379.

Fischer, G., M. Shah, and H. van Velthuizen. 2002. Climate *Change and Agricultural Vulnerability*. Special Report prepared for the World Summit on Sustainable Development, Johannesburg.

Frankenhauser, S. 1995. *Valuing Climate Change: The Economics of the Greenhouse.* London: Earthscan Publications.

Gan, T.Y. 2000. Reducing vulnerability of water resources of Canadian Prairies to potential droughts and possible climatic warming. *Water Resources Management*, 14 (2): 111-135.

Gregory, J.M., J.F.B. Mitchell, and A.J. Brady. 1997. Summer drought in northern mid-latitudes in a time dependent CO2 experiment. *Journal of Climate,* 10(4): 662-686.

Guiterrez, A. 2004. Insect Pests and Population Dynamics. In D. Wolfe (ed.), *Proceedings: Impacts of Climate Change on Horticulture Symposium*; Nov 2, 2003, Providence, RI.

Guo, Q. 2000. Climate change and biodiversity conservation in Great Plains agroecosystems. *Global Environmental Change Part A: Human and Policy Dimensions,* 10(4): 289-298.

Hatfield, J. and J. Prueger. 2004. Impacts of changing precipitation patterns on water quality. *Journal of Soil and Water Conservation*, 59(1): 51-58.

Hogg, T., G. Weiterman, and L.C. Tollefson. 1997. Effluent Irrigation: Saskatchewan Perspective. CSIDC Publication. http://www.agr.gc.ca/pfra/csidc/csidpub5_e.htm

Holloway, L.E. and B.W. Ilbery. 1996. Farmer's attitude towards environmental change, particularly global warming, and the adjustment of crop mix and farm management. *Applied Geography,* 16: 159-171.

IPCC (Intergovernmental Panel on Climate Change). 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. http://www.ipcc.ch/

IPCC (Intergovernmental Panel on Climate Change). 2001. *Climate Change 2001. Working Group 1: The Scientific Basis*. http://www.gridano/climate/ipcc_tar/wg1/380.htm

Kandlikar, M. and J. Risbey. 2000. Agricultural impacts of climate change: if adaptation is the answer, what is the question? *Climatic Change,* 45: 529-539.

Kane, S., J. Reilly, and J. Tobey. 1992. An empirical study of the economic effects of climate change on world agriculture. *Climate Change,* 21: 17-35.

Kelly, P.M., and W.N. Adger. 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change,* 47: 325-352.

Ker, A.P. and P. McGowan. 2000. Weather-Based Adverse Selection and the U.S. Crop Insurance Program: the private insurance company perspective. *Journal of Agricultural and Resource Economics,* 25(2): 386-410.

Klein, R.J.T. and D.C. MacIver. 1999. Adaptation to climate variability and change: methodological issues. *Mitigation and Adaptation Strategies for Global Change,* 4: 189-198.

Kling, G. , K Hayhoe, L. Johnson, J. Magnuson, S. Polasky, S, Robinson, B. Shuter, M. Wander, D. Wuebbles, and D. Zak. 2003. *Confronting Climate Change in the Great Lakes Region*. A report of the Union of Concerned Scientists and the Ecological Society of America.

Koshida, G. and W. Avis (eds.). 1998 *Canada Country Study: Climate Impacts and Adaptation.* Government of Canada. http://www.climatechange.gc.ca/english/publications/ccs/

Kulshreshtha S. and C. Grant. 2003. Economic impact assessment of irrigation development and related activities in Manitoba**.** *Canadian Water Resources Journal,* 28(1): 87-95.

Kurukulasuriya, P. and S. Rosenthal. 2003. *Climate Change and Agriculture: A Review of Impacts and Adaptations*. Paper No. 91, World Bank Environment Department.

Lanterman, W. 2002. Director, Centre for Plant Health (CFIA), Sydney, B.C. Personal communication with E. Wall, June 23.

Leary, N. 1999. A Framework for benefit-cost analysis of adaptation to climate change and climate variability. *Mitigation and Adaptation Strategies for Global Change,* 4(3-4), 307-318.

Lee, J.J., D.L. Phillips and V.W. Benson 1999. Soil erosion and climate change: assessing potential impacts and adaptation practices. *Journal of Soil and Water Conservation*, 54(3): 529-536.

Lewandrowski, J. and R. Brazee. 1003. Farm programs and climate change. *Climatic Change,* 23: 1-20.

Lewandrowski, J. and D. Schimmelpfennig .1999. Economic Implications of Climate Change for U.S Agriculture: Assessing recent evidence. *Land Economics*, 75(1): 39-57.

Lobell, D. and G. Asner. 2003. Climate and management contributions to recent trends in agricultural yields. *Science,* Feb 14.

Loladze, I. 2002. Rising atmospheric CO_2 and human nutrition: toward globally imbalanced plant stoichiometry? *Trends in Ecology and Evolution,* 17(10): 457-461.

Luo, Q. and E. Lin. 1999. Agricultural vulnerability and adaptation in developing countries: the Asia-Pacific region. *Climatic Change,* 43: 729-743.

MacIver, D. C. and F. Dallmeier. 2000. Adaptation to climate change and variability: adaptive management. *Environmental Monitoring and Assessment,* 61: 1-8.

Mahul, O. and D. Vermersch. 2000. Hedging crop risk with yield insurance futures and options. *European Review of Agricultural Economics*, 27(2): 109-126.

McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press: Cambridge, UK.

McGinn, S.M., A. Toure, O.O. Akinremi, D.J. Major, and A.G. Barr. 1999. Agroclimate and crop response to climate change in Alberta, Canada. *Outlook on Agriculture*, 28 (1): 19-28.

McKenney, M.S., W.E. Easterling, and N.J. Rosenberg. 1992. Simulation of crop productivity and responses to climate change in the year 2030: the role of future technologies, adjustments and adaptations. *Agricultural and Forest Meteorology*, 59(1-2): 103-127.

Mehlman, S. 2003. *Historical and Projected Temperature and Precipitation Trends in the Annapolis Valley, Nova Scotia*. Technical Report for the AnnapolisValley Climate Change Policy Response Pilot Project, Clean Annapolis River Project.

Meinert, B. 2003. Presentation for *Meeting the Challenges of Climate Change.* Roundtable Session sponsored by C-CIARN Agriculture and C-CIARN Prairies at Grain World 2003, Winnipeg Manitoba.

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. The impact of global warming on agriculture: a Ricardian analysis. *American Economic Review,* 84: 753-771.

Mooney, S. and L.M. Arthur. 1990. The impacts of climate change on agriculture in Manitoba. *Canadian Journal of Agricultural Economics,* 38: 685-694.

Nagy, C. 2001.*Agriculture Energy Use of Adaptation Options to Climate Change*. A report to PARC (Prairie Adaptation Research Collaborative).

Natural Resources Canada, 2002. *Climate Change Impacts and Adaptation: A Canadian Perspective: Agriculture*. Produced by the Climate Change Impacts and Adaptation Directorate, Nearing, M., F. Pruski, and M. O'Neal. 2004. Expected climate change impacts on soil erosion rates: a review. *Journal of Soil and Water Conservation*, 59 (1): 43-50.

Neilsen, D., S. Smith, W. Koch, J. Hall, and P. Parchomchuk. 2002. *Impact of Climate Change on Crop Water Demand and Crop Suitability in the Okanagan Valley, British Columbia*. Final report submitted to the Climate Change Action Fund.

Newman, J.E. 1980. Climate change impacts on the growing season of the North American Corn Belt. *Biometeorology,* 7:128-142.

Nordhaus, W. and J. Boyer. 2000. *Warming the World: Economic Models of Global Warming*. Cambridge: MIT Press.

Nyirfa, W.N.; Harron, B. 2002. *Assessment of Climate Change on the Agricultural Resources of the Canadian Prairies*. Report submitted to the Prairie Adaptation Research Collaborative (PARC).

Ownesby, C. R. Cochran, and L. Auen. 1996. Effects of elevtaed carbon dioxide on forage quality for ruminants. In C. Koerner and F. Bazzaz (eds.), *Carbon Dioxide, Populations, and Communities*. Academic Press, 363-371.

Parry, M.L. 1990. *Climate Change and World Agriculture*. London: Earthscan.

Pattey, E., I. B. Strachan, J. B. Boisvert, R. L. Desjardins, and N. B. McLaughlin. 2001. Detecting effects of nitrogen rate and weather on corn growth using icrometeorological and hyperspectral reflectance measurements. *Agriculture and Forest Meteorology,* 108(2): 85-164.

Peet, M. 2004. Yield and quantity responses of horticultural crops to CO_2 and temperature. In D. Wolfe (ed.), *Proceedings: Impacts of Climate Change on Horticulture Symposium*; Nov 2, 2003, Providence, RI.

PFRA (Prairie Farm Rehabilitation Authority). 2003. *Watch for Sulphates and Blue-Green Algae in Cattle Water Supplies*. http://www.agr.gc.ca/pfra/drought/article_e.htm

Polsky, C., D. Schroder, A. Patt, S. Gaffin, M. L. Martello, R. Neff, A. Pulsipher and H. Selin. 2003. *Assessing Vulnerability to the Effects of Global Change: An Eight Step Approach*. Boston: Belfer Center for Science & International Affairs, Harvard University.

Ramsey, D. and M. Tarleton. 2004. Unpublished findings from focus groups for research project *Farm-level Adaptation to Multiple Risks: Climate Change and Other Concerns*. Department of Rural Development, Brandon University.

Rees, H., E. Chow, P. Loro, J. Lavoie, J. Monteith, and A. Blaauw. 2002. Hay Mulching to reduce runoff and soil loss under intensive potato production in Northwestern New Brunswick, Canada. *Canadian Journal of Soil Science, 249-258*.

Reid, S. 2003. *Winds of Change. Farm-level Perception and Adaptation to Climate Risk in Perth County, Ontario.* Unpublished Masters Thesis. Rural Planning and Development, University of Guelph.

Reinsborough, M. 2003. A Ricardian model of climate change in Canada. *Canadian Journal of Economics,* 3: 21-40.

Reilly, J. 1995. Climate change and global agriculture: recent findings and issues. *American Journal of Agricultural Economics,* 77:727-733.

Reilly, J., J Graham, and J. Hrubovcak. 2001. *Agriculture: The Potential consequences of Climate Variability and Change for the United States, U.S. National Assessment of the Potential Consequences of Climate Variability and Change, US Global Change Research Program.* New York: Cambridge University Press.

Reilly, J. and D. Schimmelpfennig. 1999. Agricultural impact assessment, vulnerability, and the scope for adaptation. *Climatic Change*, 43: 745-788.

Risbey, J., M. Kandlikar, H. Dowlatabadi, and D. Graetz. 1999. Scale, context, and decision making in agricultural adaptation to climate variability and change. *Mitigation and Adaptation Strategies for Global Change,* 4: 137-165.

Rosenberg, N. 1981. Technologies and strategies in weatherproofing crop production. In L.E. Slater and S.K. Levins (eds.), *Climates Impact on Food Supplies: Strategies and Technologies for Climate-Defensive Food Production.* Boulder: Westview Press, 157-180.

Rosenzweig, C. 1990. Crop response to climate change in the southern Great Plains: A simulation study. *Professional Geographer,* 42: 20-39.

Rosenzweig, C., A. Iglesias, X. Yang, P.Epstein, and E. Chivian. 2000. *Climate Change and U.S. Agriculture: The Impacts of Warming and Extreme Weather Events on Productivity, Plant Diseases and Pests.* Boston: Centre for Health and the Global Environment, Harvard Medical School.

Rosenzweig, C. and M.L. Parry. 1994. Potential impacts of climate change on world food supply. *Nature,* 367: 133-138.

Sapirstein, H., P. Bullock, M. Entz, D. Fernando, J. Dexter, and R. DePauw. 2002. *CWRS Wheat Grade and Quality Response to Growing Season Weather Variation in the Prairie Region – New Knowledge for Production and Delivery of Uniform Quality Wheat to Market.* Research Project Report, University of Manitoba.

Sauchyn, D.J. and A.B. Beaudoin 1998. Recent environmental change in the southwestern Canadian plains. *The Canadian Geographer,* 42(4) 337-353.

Sauchyn, D., E. Barrow, R. Hopkinson, and P. Leavitt. 2003. *Aridity on the Canadian Plains: Future Trends and Past Variability.* PARC Document #03-01. http://www.parc.ca/publications.htm

Sauchyn, D. 2003. Information in Transcript for Standing Senate Committee on Agriculture and Forestry hearings. (Issue #6, Feb 4, 2003)

Schweger, C. and C. Hooey. 1991. Climate change and the future of prairie agriculture. In J. Martin (ed.), *Alternative Futures for Prairie Agricultural Communities.* Edmonton: University of Alberta, 1-36.

Shortt, R., W. Caldwell, J. Ball, and P. Agnew. 2004. A participatory approach to water management: irrigation advisory committees in southern Ontario. Paper presented at 57th *Canadian* Water Resources Association Annual Congress. Montreal, Quebec.

SSCAF (Standing Senate Committee on Agriculture and Forestry). 2003. *Climate Change: We Are At Risk*. Final Report, Ottawa.

Singh, B., and R.B. Stewart. 1991. Potential impacts of a CO_2 induced climate change using the GISS scenario on agriculture in Quebec, Canada. *Agriculture, Ecosystems and Environment,* 35: 327-347.

Singh, B., M. El Maayar, P. Andre, C.R. Bryant, and J.P. Thouez. 1998. Impacts of a GHG-induced climate change on crop yields: effects of acceleration in maturation, moisture stress and optimal temperature. *Climatic Change*, 38 (1): 51-86.

Slovic, P. 2000. *The Perception of Risk*. Sterling, VA: Earthscan.

Smit, B. 1991. Decisions in agriculture in the face of uncertainty: role of climate impact assessment. In P. Dzikowskil (ed.), *Changing Climate in Relation to Sustainable Agriculture.* Proceedings from Canadian Society of Agrometeorology, Fredericton, NB, July.

Smit, B. 1999. *Agricultural Adaptation to Climate Change: A report to the Adaptation Liaison Office.* May 31.

Smit, B., L. Ludlow, and M. Brklacich. 1988. Implcations of a global climatic warming for agriculture: a review and Appraisal. *Journal of Environmental Quality,* 17: 519-527.

Smit, B., M. Brklacich, R.B. Stewart, R. McBride, M. Brown and D. Bond. 1989. Sensitivity of crop yields and land resource potential to climatic change in Ontario. *Climatic Change,* 14: 153-174.

Smit, B. and M. Brklacich. 1992. Implications of global warming for agriculture in Ontario. *The Canadian Geographer,* 36: 75-78.

Smit, B., D. McNabb, and J. Smithers. 1996. Agricultural adaptation to climatic variation. *Climatic Change,* 33: 7-29.

Smit, B., R. Blain, and P. Keddie. 1997. Corn hybrid selection and climatic variability: gambling with nature? *The Canadian Geographer,* 41: 429-438.

Smit, B., I. Burton, R.J.T. Klein, and R. Street. 1999. The science of adaptation: a framework for assessment. *Mitigation and Adaptation Strategies for Global Change,* 4: 199-213.

Smit B., I. Burton, R. Klein, and J. Wandel. 2000a. An anatomy of adaptation to climate change and variability. *Climatic Change,* 45: 223-251.

Smit, B., E. Harvey, and C. Smithers. 2000b. How is climate change relevant to farmers? In D Scott, B. Jones, J. Audrey, R. Gibson, P. Key, L. Mortsch, and K. Warriner (eds.), *Climate Change Communication: Proceedings of an international conference.* Kitchener-Waterloo, Canada, 22-24 June. Environment Canada: Hull, Quebec, F3-18- F3-25.

Smit, B. and O. Pilifisova. 2002. From adaptation to adaptive capacity and vulnerability reduction. In S. Huq, J. Smith, and R.T.J. Klein (eds.). *Enhancing the Capacity of Developing Countries to Adapt to Climate Change.* London: Imperial College Press.

Smit, B. and M.W. Skinner. 2002. Adaptation options in agriculture to climate change: a typology. *Mitigation and Adaptation Strategies for Global Change,* 7: 85-114.

Smit, B. 2003. Current coping strategies and adaptation to climate change. Presentation at UNFCCC Expert Workshop on Local Coping Strategies, New Delhi., Nov. 11-12.

Smithers, J. and A. Blay-Palmer. 2001. Technology innovation as a strategy for climate change adaptation in agriculture. *Applied Geography*, 21: 175-197.

Smithers, J. and B. Smit. 1997. Human adaptation to climatic variability and change. *Global Environmental Change,* 7: 129-146.

Smithers, J. and B. Smit. 1997. Agricultural system response to environmental stress. In B. Ilbery, Q. Chiotti and T. Rickard (eds.), *Agricultural Restructuring and Sustainability*. Wallingford: CAB International, 167-183.

Soskolne C., K. Smoyer-Tomic, D. Spady, K. McDonald, J. P. Rothe, and J. Klaver. 2004. *Climate Change, Extreme Weather Events and Health Effects in Alberta*. Final report for Health Policy and Research Program Health Canada, Ottawa. http://www.phs.ualberta.ca/climatechange/

Southworth, J., J. C. Randolph, M. Habeck, O.C. Doering, R.A. Pfeifer, D.G. Rao, and J.J. Johnston. 2000. Consequences of future climate change and changing climate variability on maize yields in the midwestern United States. *Agriculture, Ecosystems and Environment,* 82: 139-158.

Statistics Canada. 2003. *The Daily* for Aug. 26. http://www.statcan.ca/Daily/English/030826/d030826a.htm

Strzepek, K. D. Major, C. Rosenzweig, A. Iglesias, D. Yates, A. Holt, D. Hillel. 1999. New Methods of Modeling Water availability for Agriculture under Climate Change: The U.S. Cornbelt. *Journal of the American Water Resources Association.* 35(6): 1639-1655.

SWCS (Soil and Water Conservation Society). 2003. *Conservation Implications of Climate Change: Soil Erosion and Runoff.* Report released at the 2003 American Association for the Advancement of Science (AAAS) conference in Denver, Colorado.

Tan, C.S. and W.D. Reynolds. 2003. Impacts of recent climate trends on agriculture in southwestern Ontario. *Canadian Water Resources Journal*, 28:1: 87-95.

Thacker, P. 2004. As the planet heats up will the topsoil melt away? *Journal of Soil and Water Conservation*, 59(1): 13A-25A.

Thorpe, J., S. Wolfe, J. Campbell, J. LeBlanc, and R. Molder. 2001. *An Ecoregion Approach for Evaluating Land Use Management and Climate Change Adaptation Strategies on Sand Dune Areas in the Prairie Provinces.* Prairie Adaptation Research Collaborative Project, Regina.

Tollenaar, M., D. E. McCullough, et al. .1994. Physiological basis of the genetic improvement of corn. In G.A. Slater (ed.), *Genetic Improvement of Field Crops.* New York: Marcel Dekker,183-236.

Tollenaar, M. and J. Wu. 1999. Yield improvement in temperate maize is attributable to greater stress tolerance. *Crop Science,* 39: 1597-1604.

Tokariuk,….2003…sugar beet research on the web..

Turvey, C. 2001 Weather derivatives for specific event risks in agriculture**.** *Review of Agricultural Economics*, 23(2): 333-351

Tyrchniewicz, A. and B. Yusishen. 2000. *Agriculture and Climate Change*. Workshop report available from International Intitute for sustainable Development (IISD), Winnipeg Manitoba.

Tyrchniewicz, E. 2003 Submission to Standing Senate Committee on Agriculture and Forestry, Ottawa, Feb 20.

UNFCC (United Nations Framework Convention on Climate Change). 1992. *United Nations Framework Convention to Climate Change: Text.* Geneva: World Meteorological Organization and United Nations Environment Program.

USDA (United States Department of Agriculture), 1999. *Managing Risk in Farming: Concepts, Research and Analysis.* Economic Research Service. Agricultural Economics Report No. 774. http://www.ers.usda.gov/publications/aer774/

Van Herk, J. 2001. Presentation in summary report for Risks and Opportunities from Climate Change for the Agricultural Sector. Workshop sponsored by Farming Systems Research, University of Guelph, March. Document available through C-CIARN Agriculture.

Van Kooten, G.C. 1995. Climatic change and Canada's boreal forest: socio-economic issues and implications for land use. *Canadian Journal of Agricultural Economics*, 43: 167-183.

Wall, E. and B. Smit. 2004 (forthcoming).Climate Change Adaptation in Light of Sustainable Agriculture. *Journal of Sustainable Agriculture.*

Wandel, J. and B. Smit. 2000. Agricultural risk management in light of climate variability. In H. Millward, K. Beesley, B. Ilbery, and L. Harrington (eds.). *Agricultural and Environmental Sustainability in the New Countryside*. Winnipeg: Hignell , 30-39.

Weber, M. and G. Hauser. 2003. A regional analysis of climate change impacts on Canadian Agriculture. *Canadian Public Policy*, June: 163-179.

Williams, G.D.V., R.A. Fautley, K.H. Jones, R.B. Stewart, and E.E. Wheaton. 1988. Estimating effects of climatic change on agriculture in Saskatchewan. In M.L. Parry, T.R. Carter and N.T. Konjin (eds.), *The Impact of Climatic Variations on Agriculture, Volume I: Assessments in Cool Temperate and Cold Regions.* Dordrecht: Kluwer Academic, 219-379.

Williams, G.D.V. and E.E. Wheaton. 1998. Estimating biomass and wind erosion impacts for several climatic scenarios: a Saskatchewan case study. *Prairie Forum*, 23 (1): 49-66.

Willows, R.I. and and R.K. Connell (eds.). 2003. *Climate Adaptation: Risk uncertainty and Decision-making.* UKCIP (United Kingdom Climate Impacts Programme) Technical Report, UKCIP, Oxford, England.

Winkler, J., J Andresen, G. Guentchev, J. Picardy, and E. Waller. 2000. Focus: climate change and fruit production: an exercise in Downscaling. In *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change in the Great Lakes Region,* Great Lakes Regional Assessment (Agriculture). http://www.geo.msu.edu/glra/assessment/assessment.html

Winkler J., J. Andresen, G. Guentchev, and R. Kriegel. 2002. Possible impacts of projected temperature change on commercial fruit production in the Great Lakes Region. *Journal of Great Lakes Research,* 28(4): 608-625.

Wolfe, D.W. 2003. *Proceedings: Impacts of Climate Change on Horticulture Symposium*; Nov 2, 2003, Providence, RI. http://www.hort.cornell.edu/department/faculty/wolfe/cchortproc.pdf

Wolfe, D. undated. Potential impact of climate change on agriculture and food supply. Article available through United States Global Change Research Program. http://www.gcrio.org/USGCRP/sustain/wolfe.html

Yohe, G. and R.S.J. Tol. 2002. Indicators for social and economic coping capacity- moving toward a working definition of adaptive capacity. *Global Environmental Change*, 12

Zavaleta, E., M.R. Shaw, N.R. Chiariello, H.A. Mooney, and C.B. Field. 2003. Additive effects of simulated climate changes, elevated CO_2, and nitrogen deposition on grassland diversity. *Proceedings of the National academy of Sciences,* 100(13): 7650-7654.

Zentner, R., C. Campbell, V. Biederbeck, P. Miller, F. Selles, and M. Fernandez. 2001. In search of a sustainable cropping system for the semiarid Canadian Prairies. *Journal of Sustainable Agriculture,* 18(2/3): 117-136.

Ziska, L. 2004. Invasive weeds. In D. Wolfe (ed.), *Proceedings: Impacts of Climate Change on Horticulture Symposium*; Nov 2, 2003, Providence, RI.

APPENDIX A

INFORMATION ABOUT C-CIARN AGRICULTURE

C-CIARN Agriculture is part of a national network supported by the government of Canada and is committed to facilitating and promoting research into climate change risks and adaptation for the Canadian agri-food sector. We offer a forum for those in industry, research, and policy to learn from each other and work together on effective climate risk management strategies. (Details are available through: http://www.c-ciarn.uoguelph.ca/).

National Advisory Committee

- Brian Abrahamson, Prairie Farm Rehabilitation Administration
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- Don McCabe, Grain Growers of Canada
- Dave Sauchyn, Prairie Adaptation Research Collaborative

Barry Smit, Scientific director
Ellen Wall, Coordinator
Johanna Wandel, Associate
Stefanie Neumann, Assistant

APPENDIX B

ACRONYMS FOR MODELS USED IN THE PAPER

- CGCM (Canadian Global Coupled Model or Canadian Global Circulation Model[1]. Different versions are noted with the appropriate numeral, for example CGCMI, CGCMII.
- HadCM2, HadCM3 (Hadley Centre Coupled Model) [2]
- GFDL (Geophysical Fluid Dynamics Laboratory,)[3]
- GISS (Goddard Institute for Space Studies)[4]
- IISA (International Institute for Applied Systems Analysis)
- OSU (Oregon State University General Circulation Model)
- PCM (Parallel Climate Model)[5]
- UKMO (United Kingdom Meteorological Office General Circulation Model)
- MPI (Max Planck Institute Circulation Model)
- ECHAM4 (German)
- CSIRO

Add following only if used directly somewhere--

- CCSR-98 (Centre Climate Research Studies--Japan)
- NCAR-PCM3 (National Centre for Atmospheric Research – USA
- CSIROMk2b (Commonwealth Scientific and Industrial Research Organization)

[1] Information about the development of this model is available from the Canadian Centre for Climate Modelling and Analysis (CCCma) http://www.cccma.bc.ec.gc.ca/models/cgcm1.shtml

[2] Note Hadley centre is in England?

[3] developed at Princeton University

[4] GISS is affiliated with NASA (National Aeronautics and Space Association)

[5] from US Department of Energy and US National Center for Atmospheric Research.

APPENDIX C

Table 7: Selected Impacts of Climatic Variability and Farmers Responses on Perth County Farms

Climate Attribute	Impact on Farm	Farmer Response
Good Weather Hot sunny weather, timely rains	• improved yield	• stockpile hay, grain • don't do anything differently • plan for a good crop • make improvements: more storage pay down debt, buy more land
Hot summers	• high heat units • hard to work in field, fainted from heat	• plant longer day corn, beans • wait for cooler weather to work in field
Hot and humid	• high humidity when wheat flowering: fusarium in wheat	• spray wheat when flowering • crop insurance
Cold and wet	• low heat units • poor quality crops • corn rust • corn wouldn't dry down • trouble making hay Ran out of hay • chemicals don't work as well	• change cultivar mix wrt heat requirements • crop insurance • buy feed • insure corn the following year • plant lower heat units the following year • plow down corn • use corn for feed • make haylage • rely on neighbours for hay • sell land following year • reduce chemical use
Warm winters	• risk of alfalfa or winter cereals being damaged • watch for insects (precaution) • spring is drier	• do nothing • plant seeds deeper
Cold winter, no snow	• lost winter wheat	• crop insurance
Length of Growing Season		• plant longer day corn
Late fall	• better crop • not as physically demanding • easier on equipment	• harvest later
Dry spring	• seeds need moisture	• plant to moisture

Drought	• aphids on soybeans: lost half the yield • aphids brought lady bugs, lady bugs affected yield • weeds don't respond to herbicide • pastures don't grow back • no extra forages to sell • hay doesn't grow back Not as much hay • poor crops • corn ready to harvest earlier	• use good management practices • tile draining • plant drought-resistant varieties / cultivars • adjust plant varieties • soil conditioning • no-till • plow at night to retain moisture • crop insurance / draw on NISA • change herbicide/pesticide applications • keep extra grain, hay, silage • more acres in forages next year • only get first and second cut • don't sell hay • buy grain
Dry Fall	• dry beans hard on machinery	
Wet	• rust in grain • trouble making hay • takes more power to work field • crop drowned	• soil conditioning • change rotation • use red clover as cover crop • pasture cattle on hay field • don't cut hay at all • tile draining • crop insurance
Wet Spring	• hard to plant crop • drowned crops	• muck it in • replant • crop insurance • wait it out
Wet Fall	• lost bean crop • poor corn • harvesting on wet ground packs soil	• use crop for feed • stop growing beans • tile draining • crop insurance • plow down crop • rely on storage capacity to keep feed • make cob meal / silage
More Snow	• more moisture on land in spring	• less tilling in spring • roll soil • seed deeper

APPENDIX D

Table 8: Selected Production Practices that Help Manage Climate-Related Risks, Manitoba Farms

Topic	**Detail**
Diversify crops and varieties	•Grow faster maturing crops •Grow less wheat and more other species due to fusarium on wheat (fusarium is moisture dependent) •Grow crops more suited to farm micro-climate •Change to forage oats from alfalfa to take advantage of moisture in farm area •Grow drought resistant varieties •Grow shorter varieties to prevent wind damage •Experiment with several varieties of same species to compare yield and quality •Grow many different species in same year to cover all bases with weather.
Intensified operations	•Increase cattle because more moisture allowed more hay production •Grow more, slower maturing grains because of increased growing season •Add more cattle and reduced cropping because of weather uncertainty •Intensify silage operation to lessen effects of moisture on feed production •Add more alfalfa because crop was assured over others •Use rotational grazing allowed more intense use of pasture •Use continuous cropping with no summer fallow
Altered practices and location	•Put more land into pasture and moved cattle on to it because of either increased moisture or risks associated with grain crops •Move to higher ground to avoid wet areas •Eliminate cattle operation because extreme weather necessitated late calving which subsequently caused conflicts with seeding •Adopt zero tillage to prevent erosion problems due to rain and wind •Return to traditional method when zero till proved difficult in wet years •Use any combination of tillage depending on soil temperature, moisture. • Add irrigation systems because of reduced moisture
Timing changes	•Get on land as early as possible •Seed later maturing crops first •Seed later to avoid late spring frosts because growing season is longer •Calving is later now as low spring temperatures do not allow pasture to start up quickly •Plant winter wheat in order to harvest sooner and avoid fall frosts •Sow later to help abate weed growth (organic) •Only sow after there has been some moisture (market garden) •Keep crop covered (strawberries) covered until danger of frost had passed for season.
Crop insurance and income stabilization	• Crop insurance and NISA very common • "Off-farm" income very common
Diversify operations	•More cattle, horses, other livestock •Seed cleaning •Outfitting •Gravel and sand •More grain types •Some farmers indicated more specialization (got rid of stock to free up time for spring work