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Sustainability and the Environment

Edited by Ellen Wall, Barry Smit, and Johanna Wandel

Farming in a Changing Climate: Agricultural Adaptation in Canada

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Abbreviations

BSE	Bovine spongiform encephalopathy
C-CIARN	Canadian Climate Impacts and Adaptation Research Network
CERES	Crop Environment Resource Synthesis
CGCM	Canadian Global Coupled Model with versions (e.g., CGCM1 and CGCM2)
CGCMI-A	Canadian Global Coupled Model that includes the effects of aerosols
CSIROMk2	Commonwealth Scientific and Industrial Research Organisation Mark 2
EPIC	Erosion Productivity Impact Calculator
FAO	Food and Agriculture Organization
FAQ	Financière agricole du Québec
GCM	Global Climate Model or Global Circulation Model
GDD	Growing degree days
GDP	Gross domestic product
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse gas
GISS	Goddard Institute for Space Studies
HadCM	Hadley Centre Coupled Model; also HadCM2, HadCM3
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LSRS	Land Suitability Rating System
MPI	Max Planck Institute Circulation Model
NGO	Non-governmental organization
P	Precipitation
PCM	Parallel Climate Model
PE or PET	Potential evapotranspiration
PFRA	Prairie Farm Rehabilitation Administration
RCM	Regional Climate Model

SDSM	Statistical Downscaling Model
SRES	Special Report on Emission Scenarios
SSRB	South Saskatchewan River Basin
UKMO	United Kingdom Meteorological Office
UPA	Union des Producteurs Agricoles du Québec

Preface

Extreme weather events have taken a substantial toll on human livelihoods and lives around the globe, and have often detrimentally affected food production and security. In 2005, persistent droughts in several African countries severely limited food supplies, flooding in Bangladesh routinely disrupted agriculture, heat spells in Australia caused crop and livestock losses, and North American hurricanes such as Katrina led to significant crop losses and blocked grain transportation systems. With climate change, the expectation is that temperatures will rise, moisture conditions will change, and many extreme climate events will become more common. Given the effects of recent extreme weather, questions arise about the capacity of agri-food systems to handle changed climate and weather in the future. Such capacity may be found in individuals and families, local communities, regional authorities, business and corporations, and/or national governments. All have a part to play in preparing for challenges – both risks and opportunities – from future climatic and weather conditions.

In Canada, indications are that climate change is already having an effect on farming, thereby increasing the need for research and programs to assist adaptive decision making. Several groups in the Canadian agri-food sector seek relevant and timely information. One is industry-related, including producers and agribusiness interests who view climate and weather risks as one of several factors to be considered in operating strategies affecting farm production practices and financial management. Another is made up of policy makers charged with the task of developing programs and legislation that can enhance the agri-food sector's ability to manage climate risks and take advantage of opportunities. A third group is the research community, which seeks to improve the understanding of the implications of climate change for the agri-food sector and to provide a sound basis for making decisions about adaptive strategies.

To date, information about climate change impacts and adaptation has for the most part been fragmented, in terms of both the issues focused on (for instance, temperature, crops, adaptive strategies) and location, with some areas in Canada receiving more attention than others. Notwithstanding the interconnections among research focus and region, there has been little opportunity to compare different research perspectives, analytical methods, and results relevant to climate change adaptation in Canada's agri-food sector. To address these knowledge gaps, C-CIARN Agriculture (Canadian Climate Impacts and Adaptation Research Network for Agriculture) sponsored a workshop in Edmonton, Alberta, on 17 February 2005. At this event, leading Canadian scholars and researchers presented and critiqued their latest research findings on climate change adaptation and agriculture. A panel of agricultural producers and policy makers also offered their comments on the utility of the results presented.

This book is a direct result of that workshop; it provides a review and summary of the current state of knowledge about climate change impacts and adaptation for the Canadian agri-food sector. It 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. Material presented in this volume provides a comprehensive look at the issues and research relevant to anyone interested in climate change and agricultural adaptation.

This book is divided into five parts. The first is devoted to introductory issues, including information on different research approaches for studying climate change adaptation and agriculture. Three dominant research perspectives are noted and form the basis for organizing the material presented in the next three parts. Part 2 presents research findings that consider adaptation using scenario-based impact approaches. Part 3 illustrates research that places climatic stresses in the context of the many forces that influence agriculture. The research described in Part 4 is also contextual, focusing on farm-level sensitivities and adaptation processes. The conclusion in Part 5 includes comments from representatives of the agriculture industry and policy makers.

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We also wish to express our gratitude to the many agricultural producers who often gave us the benefit of their time and experience in our attempt to understand the complexities of agricultural adaptation and climate change in Canada. We trust that our interpretations will be useful and contribute in some way to the future prosperity of the Canadian agri-food sector.

Part 1:
Research Approaches to Climate Change Adaptation

Chapters 1 to 4 outline the issues underlying climate change adaptation research in agriculture and offer ways to differentiate among approaches to understanding those issues. The classification employed is an organizing principle for presenting research findings relevant to climate change adaptation in Canadian agriculture. The approaches are not mutually exclusive, but the various studies tend to rely mainly on one of the three orientations.

One approach, sometimes referred to as "top-down," starts with climate change scenarios and examines adaptations in light of the potential impacts of the specified climate changes. We label this approach "impact-based." Another perspective emphasizes the various factors (physical, economic, social, institutional) influencing adaptation decision making, and assesses climate effects in the context of those forces. This orientation is labelled "context-based." A related perspective, sometimes called "bottom-up," focuses on the process of adaptation, particularly the role of farmers and other stakeholders, and examines their capacity for managing risks and adapting to changes. We label this approach "process-based." These categories are used to distinguish the main foci of the various studies, although researchers often employ features from more than one perspective.

1
Introduction

Ellen Wall, Barry Smit, and Johanna Wandel

Climate, Weather, and Canadian Agriculture

The history of agriculture involves a continuous series of adaptations to a wide range of factors. Environmental conditions related to soil, water, terrain, and climate impose constraints and provide 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 and 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. Variable climatic and weather conditions 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) put it, "we harvest water and sunshine." Adaptation to climate and weather risks is therefore implicit in the ongoing development of the agri-food sector. With climate change, growing conditions and climate-related risks and opportunities are expected to change, and may already be changing (Rosenzweig et al. 2000).

For many, the phrase "climate change" is associated with, and related to, the analysis, policy, and action concerning increased greenhouse gas emissions and subsequent global warming (for example, Bhatti et al. 2006). Since 1997, representatives from Canadian government departments, industrial sectors, and the research community have devoted human and financial resources to developing policies and programs related to the greenhouse gas commitments under the Kyoto Protocol. Their efforts have been 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 mitigation is another climate change response or objective: 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 climatic and weather conditions (Burton et al. 2002; Smit et al. 2000b). The United Nations Framework Convention on Climate Change (UNFCCC) includes obligations related to greenhouse gas emissions reduction and carbon sequestration (mitigation), and also to adaptation: "to formulate, implement ... and regularly update ... programs containing measures ... to facilitate adequate adaptation to climate change" (Article 4.1). The UNFCCC also requires signatories to "cooperate 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) (UNFCCC 1992).

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."

Adaptation in the agri-food sector involves practices, programs, and policies that reduce vulnerabilities to climate and realize opportunities (Bryant et al. 2000). Several players are implicated in adaptation initiatives, including producers, agribusiness, and government agencies (Adger and Kelly 1999; Smit and Skinner 2002). In Canada, the Standing Senate 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).

Research to date has identified substantial risks and some opportunities from climate change for the agri-food sector across Canada. Depictions of climate change often focus on increases in temperature, suggesting that 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. 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, Québec and Ontario producers have been able to expand grain production with plant cultivar development, and expect corn and soybean production to extend to more northern regions. Although the opportunity to extend agricultural production northward is appealing and often assumed possible, soil quality, moisture availability, and other constraints may impede such developments (Kandlikar and Risbey 2000).

The focus on temperature changes reflected in the term "global warming" tends to mask other significant alterations in conditions associated with climate change, particularly changes in the frequency, magnitude, and extent of climatic extremes such as droughts and floods (Smit and Pilifosova 2003). Climate is naturally variable and agricultural systems have evolved to cope with modest variations in conditions, but they are susceptible to extremes. It appears that, in some regions, the extremes associated with climate change are pushing coping capacity to its limits. A cash crop farmer from southwestern Ontario notes:

> Weather is getting to be more sporadic and unpredictable each year. In the last three years with any luck, you probably got the best crops your farm has ever seen and if you are the other people your crops have been disastrous. Weather has been extreme and it seems to be tough to get that gentle rain that you need. Lots of areas are getting almost nothing and other areas are getting what we call hundred year storms. Something is wrong when you get three, hundred years storms in five years. (K. Oke, pers. comm.)

A fruit grower from British Columbia makes a similar observation:

> Many farmers, including myself, see hail as a big problem for us. Twenty or 30 years ago, hail events occurred maybe once every eight or ten years. My farm has been hailed seven times in the last 10 years. That is fairly typical. It is quite substantial ... All I see is that weather events are more intense, and the frequency of these weather events is increasing. This is coming at a time, unfortunately ... where our crop insurance premiums have just doubled. We have a big problem with this because with increased weather events that affect our crops and our ability to grow good quality crops, we want affordable crop insurance. (Patton 2003)

Patton's comment illustrates the fact that producers make direct links between weather conditions and farm financial management. Despite the important economic consequences from climate change, it is often characterized as primarily an environmental issue and impacts are defined in terms of temperature zones, production conditions, growing season conditions, and/or yields. As noted by Patton (2003) and Oke (pers. comm.), however, climatic and weather conditions pose risks for the financial viability of individual farming enterprises, regional agricultural sectors, and rural communities, depending on agricultural activity. Also affected are agribusiness firms that supply inputs, process outputs, and provide services, and the institutions that fund support programs related to agricultural production.

Climate change adaptation in Canadian agriculture is a topic that has a broad application and far-reaching consequences.

Adaptation Options for Managing Climate and Weather Risks

Climate change adaptations are 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 often modifications to farm practices and public policies with respect to multiple (climatic and non-climatic) stimuli and conditions.

Some climate change researchers include adaptation choices in their assessment of "impacts," recognizing that the severity of climate change risk depends on the responses of producers and other agri-food sector players. Implicit in such models is the so-called "smart farmer" assumption, namely, that producers have knowledge of climatic conditions in advance and perfect adaptations are instantaneously adopted (Adams et al. 2003; Easterling et al. 1992a; Smit 1991). For example, McKenney and colleagues (1992) assume farmers' adaptation responses for the MINK (Missouri, Iowa, Nebraska, and Kansas) region in United States. Using the EPIC (Erosion Productivity Impact Calculator) 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 that lead 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, such as 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 and colleagues (1992b) study the effectiveness of adaptation and adjustments at the farm level by running impact models (EPIC) under 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 climatic conditions offset the otherwise negative impacts, even when increased input costs are incorporated in the analysis. Easterling and colleagues (1997) also estimate the effects that shelterbelts will have for grain production under altered climatic conditions in the Great Plains region of US.

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 modelling for an average climate change 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 and colleagues (2004) 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 reduced nitrogen and energy use (Nagy 2001).

These modelling-based analyses suggest that adaptation to climate change can play a significant role in moderating impacts on the agricultural sector. By assuming one or several types of adaptations, researchers have demonstrated that climate change presents not only challenges but also opportunities for farmers. Adaptation options are an integral part of climate risk management and can be examined in terms of what is possible (typologies of adaptation strategies) and what is done (how producers adapt).

Typologies of Adaptation Strategies

Early work in identifying types of practices to deal with climatic and weather conditions designated short- and long-term measures to counteract the impact of drought in the Great Plains region of North America (Rosenberg 1981). The latter includes minimum tillage, snow management, irrigation scheduling, microclimate modification through windbreaks, diversification of crops, improved production practices (for example, 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 example, Kurukulasuriya and Rosenthal (2003) list the following as long-term strategies: 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) offer a comprehensive account of possible adaptation options for Canadian agriculture. 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 the last two (farm production practices and farm financial management) focus on farm-level management.

Diverse adaptation options for producers will ultimately depend on what is feasible and realistic (André and Bryant 2001; Bryant et al. 2000). Many of the choices available are also closely linked to practices already in place for maintaining economic and 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 2005). The concept of combining adaptation strategies with established decision-making processes that address other goals for the sector is similar to the notion of "mainstreaming" climate change adaptation with development in the international context (e.g., Huq et al. 2003).

Adaptation from Producers' Perspectives

As the research focus moves from crop yield impact models to the management of climate risks in the farm business, more attention has been focused on producers' perspectives and experience. In some studies, producers are asked to identify changes to production practices that result in benefits when faced with recent climate and weather risks. Some Ontario producers have noted that, in their opinion, climatic 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 the timing of planting, and installing irrigation systems when water availability is adequate (C-CIARN Agriculture 2002).

Also in Ontario, but with reference to soybean production only, Smithers and Blay-Palmer (2001) identify farm production practices that producers have adopted, thereby reducing risks from specific climatic stresses. Strategies include planting new or improved crop varieties that stand up under adverse climatic and weather conditions, adapting crop rotations, and altering the timing of planting.

A number of tactics have been employed to manage climate and weather-related stress at the community level. In southern Ontario, for example, 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 in light of drought stress. These include improved irrigation systems adapted from Australia, where conditions are much drier than in Ontario, to reduce the impact of extended droughts (AAFC 2003). In the 2002 season, one of the driest years in history, Ontario tomato growers with the new system had their second-highest yield ever (AAFC 2003).

Other researchers investigate specific adaptation options to explore their implications for practice and policy. For instance, Bradshaw and colleagues (2004) identify several constraints to crop diversification, including new and additional costs associated with technology required for different production systems, the pressure to specialize to meet economies of scale, better returns from diversifying "off the farm" through pluriactivity, and biophysical and locational limitations related to soil type and distance from markets. Despite such barriers, crop diversification in some regions of Canada (such as the Prairies) has taken place when viewed at the regional scale. At the individual farm level, however, there is little evidence that producers employ diversification tactics when faced with financial and production risks. 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 other factors (such as the established trend towards specialization) that can work against such actions.

Climate Change Adaptation and Agriculture Research: Different Approaches

Research into climate change adaptation began to emerge as a research focus distinct from climate change mitigation in the late 1980s and early 1990s (Smit 1993). The main concerns shaping early inquiry included identifying what adaptations would likely be employed to limit or offset impacts from climate change. Adaptation issues were also important for policy applications based on information about possible strategies and how to evaluate their merit (Smit et al. 2000b).

Research on climate change adaptation and Canadian agriculture varies according to characteristics of agriculture, such as commodity type, production system, or region, and according to the scale of analysis, from plant or plot through farm to region or globe. Adaptations can be distinguished by the type of climatic condition considered, such as temperature, moisture, or extreme events. Studies can also be grouped by their focus on physical conditions, biological variables, or social and economic processes, and whether they are primarily theoretical, modelling, or empirical analyses. Inquiry also differs according to research orientation, with some efforts contributing mainly to scientific knowledge while others are explicitly applied or policy-oriented.

This book recognizes the great variety in analyses, and differentiates them broadly according to the types of questions they are addressing and their starting points for examining adaptation. One type of inquiry focuses on four questions: "What are the impacts of expected climate change?" "How serious is climate change?" "What adaptations could possibly address the estimated impacts?" and "How much of the impacts can be moderated or offset by particular adaptations?" Research addressing these questions tends to start with selected climate change scenarios, models the impacts of these conditions on particular aspects of agriculture (commonly local agroclimatic conditions and yields), and then includes hypothetical or assumed adaptations in the modelling to estimate the "residual impacts." This "top-down" research approach is labelled here as *impact-based approach.*

A complementary perspective addresses the questions "What are the conditions that affect producers, and how do they deal with them?" "What facilitates or constrains adaptation in practice?" and "What is the context in which adaptation in agriculture occurs?" This perspective identifies the climate and non-climate forces that influence decisions in agriculture and documents the role of multiple forces (climate, economic, social, etc.) and multiple scales that define the context within which adaptation occurs. Such studies are considered here under the *context-based approach.*

A third type of research addresses the questions "How do the processes of adaptation work?" "Who makes the decisions?" "To what conditions are adaptations undertaken?" "What conditions influence the types of adaptations employed or not employed?" "What is the prospect of these adaptations being viable under future conditions?" and "What can be done to facilitate adaptation in practice?" This approach begins with understanding how the farming system experiences exposure to hazards (such as climatic conditions), how it is vulnerable, and how adaptation decisions are made. These insights into adaptation processes can be applied to assess the capacity for adaptations to future climate change. This "bottom-up" research approach, which focuses on decision making at the local scale, is referred to here as the *process-based approach.*

These three broad perspectives are used to structure this book, although many studies do not fit cleanly into a single category. Several studies primarily follow one of the approaches but incorporate elements from another. Nonetheless, these categories do provide distinct types of information about what climate change means for Canadian agriculture, how climatic conditions affect agriculture, and the prospects for adaptation in the sector.

Outline of the Contents of This Book

The focus of this book is on adaptation to climate change in Canadian agriculture. This introductory chapter has established that climate change is an important issue for the Canadian agri-food sector and has introduced three approaches for understanding agricultural adaptation to climate change. The other chapters in Part 1 provide more in-depth illustrations of these perspectives.

Chapter 2 describes the history and development of the impact-based approach, including its strengths and limitations. A survey of research employing this approach provides a comprehensive look at what impact-based research can accomplish. The conclusion to Chapter 2 points out the value of addressing underlying causes of vulnerability. This topic is examined more fully in Chapter 3, where the authors outline the context-based approach and review research results in terms of risk and the role of government programs and policy. Chapter 4 concludes Part 1 by focusing on the process-based approach. Although elements of this perspective are well established in methodologies frequently employed in social sciences, some of the practices have only recently been employed in climate change adaptation and agriculture research. Consequently, Chapter 4 provides more detail on the theoretical and conceptual elements of the process-based approach and less on results from such studies in Canadian agriculture.

Part 2 contains three examples of studies broadly following the impact-based approach for climate change and Canadian agriculture. Chapter 5 (by Samuel Gameda and colleagues) uses climate change scenarios for impact-based assessments relying on different agroclimatic indices and their implications for specific types of crop production in Atlantic and central Canada. In Chapter 6, David Sauchyn considers Prairie agriculture and presents historical data on climate impacts as well as current and future effects. Chapter 7 is based on a major impact study of the Okanagan Basin in British Columbia. In that chapter, Denise Neilsen and colleagues demonstrate how scenarios of future climate can be used to estimate impacts and engage stakeholders in discussions about adaptive responses to potential impacts.

Context-based studies are featured in Part 3. In Chapter 8, Ben Bradshaw examines how climate risks are treated in light of other risks for primary agriculture and offers insights into expected adaptations, given the historical trajectory of Canadian agriculture. Henry Venema picks up on this theme in Chapter 9 and provides specific details from Prairie agriculture to make the point that adaptive capacity for climate change impacts is embedded in a host of social and economic factors. In Chapter 10, Harry Diaz and David Gauthier focus on the importance of adaptive capacity at the institutional level, particularly contributions from government programs. They use findings from research in the South Saskatchewan River Basin to illustrate their points. Christopher Bryant and colleagues (Chapter 11) conclude Part 3 with their assessment of climate change adaptation in Québec agriculture. They offer a review of the research on the topic that leads directly to current Québec research focusing on the use of crop insurance for managing climate and weather risks and the policy implications related to that adaptation strategy.

Part 4 includes examples of studies about climate change adaptation and Canadian agriculture that follow the process-based approach. In Chapter 12, Suzanne Belliveau and colleagues reveal how British Columbia apple and grape production is subject to a host of conditions and factors that affect strategic decision making for all risks, including weather and climatic conditions. This finding is also relevant to research from Ontario presented in Chapter 13. In that chapter, Susanna Reid and colleagues document producers' experiences with climate and weather risks in a specific region of the province. Their analysis demonstrates both the wide variety of current climate adaptation strategies and their integration with existing farm practices and management issues. Cynthia Neudoerffer and David Waltner-Toews (Chapter 14) also use rural community examples for their case study of the process of building capacity and resilience in a Manitoba farming region. This examination of residents' responses to past soil erosion and flooding problems points out several features that need to be in place if and when climatic and weather conditions bring renewed stress to those areas. In Chapter 15, Robert McLeman employs a historical case study to show how climate change may affect rural agricultural population patterns. He uses community experience in Oklahoma during the 1930s Dust Bowl to demonstrate the processes underlying rural families' ability to move from the affected regions. McLeman points out that such a strategy is a form of adaptation to adverse climate and weather impacts with possible applications for contemporary and future Canadian rural agricultural communities.

The concluding section, Part 5, consists of two chapters. Chapter 16 contains observations from agricultural producers and policy representatives who attended the workshop that gave rise to this book. Their insights on climate change adaptation research for the Canadian agri-food sector are reported as verbatim commentary and organized according to three issues: Variability/Uncertainty, Capacity, and Adaptation Processes. Chapter 17 provides highlights from the material covered in the previous sixteen chapters. This summary is offered as a comprehensive overview of the issues and gaps in our knowledge regarding climate change adaptation and Canadian agriculture.

2
Impact-Based Approach

Michael Brklacich, Barry Smit, Ellen Wall, and Johanna Wandel

Human activities have been altering the chemical composition of the earth's atmosphere for several centuries (Ruddiman 2005). Increased levels of "greenhouse gases" (GHGs) such as carbon dioxide and methane are an undeniable marker of human-induced atmospheric change (Weaver 2004). GHG concentrations in the atmosphere have been increasing exponentially for about 200 years, and it is now apparent that human activities are contributing to climate changes on a planetary scale (Beade et al. 2001; Crutzen 2002).

The prospect of global climate change has sparked considerable interest in relationships between climate change and human activities in the scientific and policy communities. Given that climate is a major input to crop production, it is not surprising that agriculture has received considerable attention with respect to climate change (e.g., Parry 1990). Some of the earliest assessments of the impacts of climate change on human systems were undertaken for the agricultural sector (Adams et al. 1988; Arthur and Abizadeh 1988; Rozensweig 1985; Smit et al. 1988, 1989). Climate change and agricultural relationships featured prominently in the first three assessment reports issued by the Intergovernmental Panel on Climate Change (IPCC) (Gitay et al. 2001), and syntheses of the relationship between climate change and Canadian agriculture have been produced (Brklacich et al. 1997a; Bryant et al. 2000; and Natural Resources Canada 2002).

As noted in Chapter 1, an array of approaches and methods exist to examine the relationships between climate change and agriculture. Of particular interest in this chapter is the impact-based approach, which Dessai and Hulme (2004) refer to as the "standard approach" given its promotion by the IPCC (Carter et al. 1994) and its dominant use in assessments during the 1990s. The IPCC recommended selecting and applying climate change scenarios so that an assessment of biophysical and socio-economic impacts could be made relative to a standard set of future climatic conditions. After estimating yield impacts, researchers would then suggest possible adaptation strategies to limit the projected effects of climate change.

The purpose of this chapter is to describe and illustrate the main components of the impact-based approach and to provide an overview of climate change adaptation and agriculture research conducted from this perspective. The strengths and limitations of the approach are noted and opportunities for advancing our collective understanding of the relationships between climate change and agriculture are suggested.

Characteristics of the Climate Change Impact-Based Approach

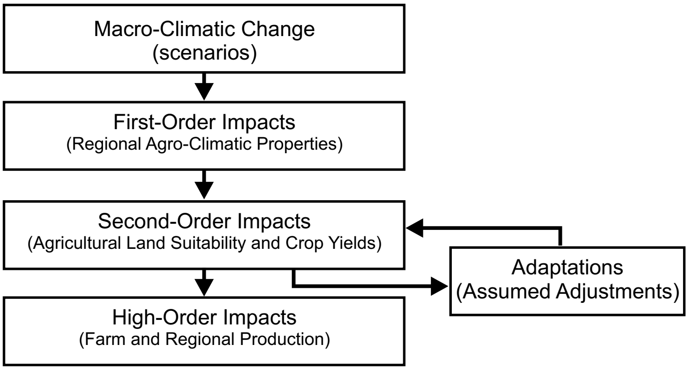
A sequential assessment of climate change/agriculture relationships typifies impact-based approaches (Figure 2.1), with the usual departure point involving the specification of a macro-climate change scenario. Macro-climate change estimates are derived from the application of General Circulation Models (GCMs) under perturbed conditions, such as the commonly used doubling of atmospheric concentrations of greenhouse gases in carbon dioxide equivalents, or "$2 \times CO_2$." A variety of GCMs are available, including the Canadian General Circulation Model (CGCM), the Goddard Institute for Space Studies (GISS) model, the United Kingdom Meteorological Office (UKMO) model, and the Hadley Centre Coupled Model (HadCM). These models typically generate estimates of future climate norms, particularly temperatures for relatively large grid cells (for example, 3° latitude by 3° longitude). Currently there are many attempts to "downscale" GCM output and provide a more detailed set of climate change estimates.

Other methods have also been employed to specify future climates, including the use of spatial and historical analogues. For example, conditions in more southerly locations in the United States act as a surrogate for southwestern Ontario under increased mean temperatures. Researchers have also used conditions from the 1930s to portray a future that is characterized by more extreme weather events, especially drought, in the Canadian Prairies. In addition, some researchers include estimated changes in ground-level CO_2 as part of a future scenario, in recognition of the role that CO_2 enrichment can play in plant growth.

Outputs from these macro-climate change scenarios are inconsistent with the data required to conduct agricultural impact assessments from at least two perspectives, and must therefore be transformed. Many agricultural sectors comprise multiple activities and are often quite heterogeneous over short distances. Hence, the relatively coarse climate change scenarios must be downscaled to a regional level. In addition, the standard climatic properties, such as changes from current monthly averages for minimum and maximum temperatures, that are included in the macro-climate scenarios need to be converted into agroclimatic parameters that are more directly pertinent to crop growth and maturity (such as start and end dates for the frost-free season and growing degree days during the frost-free season). Overall, these transformations of relatively coarse macroclimate data provide

Figure 2.1

Framework for assessing impacts of climate change



a basis for assessing the effects of human-induced climate change on regional agroclimatic properties as well as providing critical information for subsequent regional assessments of impacts on agricultural land suitability and crop yields.

Agricultural land suitability and crop yield represent two major categories of second-order impact assessments. Land suitability is the coarser of the two and provides estimates of the inherent or biological capacity of a particular location to support a major crop group, such as small grains, oilseeds, or tender fruits. The future climatic conditions are considered relative to soil, heat availability, and moisture to assess changes in land suitability for crop production. Crop yield assessments, on the other hand, are more specific and estimate the outputs (e.g., kg/ha) for a specific crop (e.g., winter wheat, canola, or apples), under the scenario's projected climate. In each case, these approaches to resource assessment employ either statistical or biophysical models that effectively compare available inputs, such as soil, heat, and moisture, with a crop's requirements for growth and maturation. The application of these models to climate change issues begins with a baseline assessment, which replicates current conditions, and then climate-sensitive parameters are adjusted to reflect a future climate. The difference between these model runs is then interpreted as the impacts stemming from the a priori specified change in climate. These approaches have been developed and refined considerably over the past twenty years. A recent study by the Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA) (Fischer et al. 2001) includes an example of the current generation of second-order impact assessments that provide insights into the possible effects of a range of climate change scenarios on cereal yields.

These assessments of the impacts of climate change on land suitability and crop yields also provide a foundation for higher-order impact assessments. For instance, future-yield estimates are used to infer economic implications and possible crop shifts. The models are initially run under current or baseline conditions. Subsequently, climate-sensitive parameters included in the farm model (e.g., crop yields, irrigation water demands) are adjusted to reflect the climates specified under the macro-climatic scenarios in order to estimate the effects of climate change on profit levels (making assumptions about input costs and product prices). On a broader scale, higher-order impact assessments can employ regional production potential models to investigate the capacity of large regions to produce major crops under current conditions and then compare these estimates of baseline potential with production potential under an altered climate.

Overall, the impact-based approach consists of sequential or hierarchical stages that commence with the specification of a macro-climate change scenario and then trace the effects of this altered climate on basic inputs to agricultural production systems, land suitability and crop yields, and, finally, regional production potential or economic returns.

Key Attributes of the Impact-Based Approach

Several attributes characterize impact-based approaches for climate change and agricultural relationships. This perspective commonly considers climate change stressors on agricultural systems and assumes that human-induced climate change will proceed slowly and incrementally over several decades. Alternatively, climate change may be considered in a comparative static way, comparing average climates several decades apart. From an agricultural perspective, the approach tends to focus on a single spatial scale, either the farm-level or a regional scale, and considers socio-economic forces in rather simplistic terms; that is, farmers are assumed to adopt certain technologies and land-use practices, and have the managerial skills (and economic and other resources) required to implement particular adaptation strategies. Finally, this approach considers the vulnerability of farms, or the agricultural sector indirectly, as residual impacts; that is, vulnerability is defined as the negative impacts that adaptation cannot ameliorate. In this context, vulnerability is viewed as a residual value (vulnerability = impacts – adaptation).

The impact-based approach is well suited to exploring the physical impacts on aspects of an agricultural system, such as crop yields or regional production potential, of such climatic stressors as changes in average seasonal heat availability. The range and variety of studies employing this approach in Canada are evident in the next section of this chapter, which contains a comprehensive overview of research conducted from the impact-based perspective. Material is presented in terms of how climate change might affect three different phenomena: agroclimatic properties, types of production, and/or types of farming systems and regional economies.

Review of Canadian Climate Change and Agriculture Research Using the Impact-Based Approach

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. 1997a). Most regions in Canada are expected to experience warmer conditions, longer frost-free seasons, and increased evapotranspiration rates:

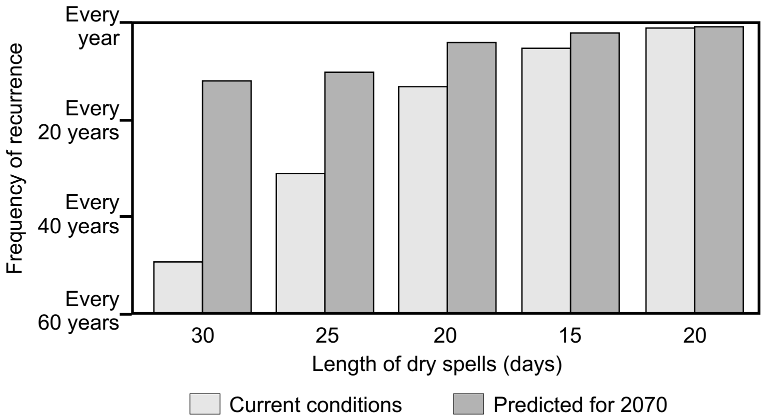
> There is strong consensus that global climate change will result in longer and warmer frost free periods across Canada and thereby generally enhance thermal regimes for commercial agriculture. These changes in agroclimatic conditions are not expected to impact regions on an equal basis, with the longest 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. 1997a, 233)

Changes in moisture conditions are expected concurrently with increased temperatures, particularly an increase in the frequency of extremes such as dry spells. Figure 2.2 illustrates that the return period for severe droughts in Western Canada is decreased with climate change. Under current climatic 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 for 20-day dry spells might decrease from once every 35 years to once every 15 years.

In most of North America, the average temperature is expected to increase and the number of rain days to decrease under most scenarios, which means that 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. Scenario projections for the Prairie region indicate

Figure 2.2

Frequency and severity of droughts in western Canada



Source: After Hengeveld (2000).

a return to historic 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 increasing dramatically (Williams et al. 1988).

Future conditions for Manitoba are similar to those for Saskatchewan, with suggestions that winters may be warmer and have less snow; summer temperatures are expected to rise; and precipitation, although reduced, may come more often in major events. It is likely that the growing season will be extended but may include more frequent extreme temperatures and severe hailstorms. Like Manitoba, Ontario and Québec are expected to have longer growing seasons (DesJarlais et al. 2004). Ontario will likely experience warmer winter and summer temperatures, increased extreme weather events (e.g., violent storms), and prolonged dry spells (Koshida and Avis 1998). Québec may experience an increase of precipitation in northern regions while levels are expected to remain constant or decrease in the southern part of the province (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 other areas 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. One way to apply the expected changes in agroclimatic properties is to examine the potential consequences they could have for crop and livestock production.

Impacts on Crop and Livestock Production

A substantial body of research goes beyond agroclimatic effects to estimate impacts on crop and livestock production in light of climate change scenarios and associated elevated levels of CO_2. This approach focuses on climate change impacts on agricultural resources and biophysical yields, usually assuming no change in technologies and management practices.

Crop Yield and Production

De Jong and colleagues (1999) use the CGCM1 (Canadian Global Coupled Model 1) to determine changes in temperature and precipitation for a number of agricultural regions across Canada. They employ the Erosion Productivity Impact Calculator (EPIC) Model to predict crop yields under the estimated climate norms. Based on the expectation of warmer and slightly wetter climatic conditions, a one- to two-week advancement of planting dates for eastern and central Canada and approximately three weeks in the west is projected. 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 yields 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 and colleagues (2001) estimate that production will be disadvantaged unless there are improvements in water supplies and irrigation efficiencies. They 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. Other challenges might arise from these factors however, such as harm to produce from extreme heat and from the persistence of pests able to survive a milder winter.

In the Prairie region, Williams and Wheaton (1998) examined potential climate change impacts for Saskatchewan based on climate models from the GISS and the IIASA. Biomass productivity and wind erosion potential were 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 that 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).

More recent analysis of the same region produces somewhat contradictory results for crop production (McGinn et al. 1999; Nyirfa and Harron 2001). Based on climate projections from the CGCM1 and crop yield estimates from EPIC, 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 percent increase in the number of growing days across the region is estimated for 2040-2069 (McGinn et al. 1999). These positive results also include effects from elevated high atmospheric CO_2. By contrast, Nyirfa and Harron (2001) used the CGCM1 in conjunction with the Land Suitability Rating System (LSRS) and concluded that constraints from moisture deficits and heat would offset the advantages of predicted precipitation increases during the same period.

Brklacich and Stewart (1995) incorporated information from the GISS, GFDL (Geophysical Fluid Dynamics Laboratory), and UKMO (United Kingdom Meteorological Office) 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 (Crop Environment Resource Synthesis): "Temperature increases would lengthen the frost-free season and reduce the risk of frost damage, but the higher temperatures would hasten the crop maturation process and thereby suppress yields. Elevated CO_2 levels would improve water use efficiency (WUE) and provide more Carbon for photosynthesis, and thereby tend to offset the potential negative effects of shortened crop maturation periods" (Brklacich and Stewart 1995, 155).

In addition, the authors examine the effects of specific adaptive strategies (irrigation, winter wheat conversion, and earlier seeding) that producers are assumed to adopt. Irrigation appears to be the most effective (if feasible and sustainable) response for offsetting losses associated with the climate scenarios. 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 (i.e., temperature and moisture stress) could suppress yields. Similar conclusions are presented in the work of Delcourt and van Kooten (1995), who employed a different circulation model, the CGCM2, and focused only on study areas in southwestern Saskatchewan (part of the Palliser's Triangle). Their analysis suggests substantial wheat yield loss and erosion of the farming economy under climate change.

For Ontario and Québec, projected changes in agroclimatic properties (based on the use of CGCM2) may have potential benefits for corn and sorghum produced in southern Québec, but these benefits are less likely for wheat and soybeans in this region (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 like those in southern Ontario. In this US case, predictions from HadCM2 (Hadley Centre Coupled Model 2) and Centre for European, Russian and Eurasian Studies (CERES) models are consistent and led researchers to conclude that corn yields in an average year would change significantly, with northern areas experiencing gains and southern regions losses. Strzepek and colleagues (1999) modelled water use and corn production using circulation models from the GISS, GFDL, and Max Planck Institute (MPI). Their analysis is based on output from WATBAL for water supply, WEAP (Water Evaluation and Planning System) for water demand forecasting, and CERES-Maize, SOYGRO, and CROPWAT for crop and irrigation modelling. They conclude that the current relative abundance of water in the region will likely be maintained up to the 2020s but find that progressively larger changes in the 2050s and beyond may compromise water availability for irrigation.

Climate models indicate that areas close to the Great Lakes Basin are expected to have a warmer, wetter climate (Andresen et al. 2000), while analysis using DAFOSYM (Dairy Forage System Model), 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 yields 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). These results focus on climate normals, however, and do not include potential effects from inadequate fertility and/or new pest infestations, which have the potential to strongly affect production. Reliance on average temperature and precipitation rates 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 the Great Lakes Basin that includes downscaling the CGCM1 and HadCM2 to finer spatial and temporal scales (Winkler et al. 2002). The authors incorporated 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 were included in estimations for codling moth development, it was not certain that climate change would bring to the area more amenable conditions for fruit production (Winkler et al. 2002). On the contrary, 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 and colleagues (2001) used the CGCM1 and concluded that it was likely that crop heat units would increase substantially. They projected increases in yields for grain and soybean with little change indicated for barley. Also relevant to eastern Canada are findings from Bélanger and colleagues (2002), who employed 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.

Additional Research on Possible Impacts on 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 of increases in temperature and precipitation, some researchers conclude that 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.

Coakley and colleagues (1999) note that there are serious issues regarding climate change and plant disease management. A review of key findings indicates that precipitation has more pronounced effects on plant disease than temperature, yet current GCMs 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). Climate change is expected to affect the incidence and severity of plant diseases 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).

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 climatic and weather conditions. For instance, Archambault and colleagues (2001) investigated 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 CO_2 but also a weakened efficacy of chemical control. Pattey and colleagues (2001) conclude that consideration of weather variables is advisable for effective nitrogen management in corn production, information that takes on more importance in light of potential change to climatic and weather conditions.

Crop production eventually results in foodstuffs for human consumption. Matters 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 lead to negative effects from the direct ingestion of plants deficient in trace minerals such as iron, zinc, chromium, and magnesium. It also has implications for human consumption of food created from animal products, if those animals are fed material that is deficient in micronutrients (Loladze 2002).

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

Forage and Livestock Production

The use of climate models and scenarios to project direct impacts on livestock is rare. Such models have been employed, however, to examine possible impacts on forage production (Adams et al. 2003) and grassland sustainability, both of which are important factors for livestock production. For instance, Baker and colleagues (1993) assessed potential effects on ecosystem processes and cattle production in US rangelands incorporating output from the GFDL, GISS, and UKMO into various ecosystem simulation models. Their analysis for the more northern regions projects a 10 percent 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 forage more and relying less on food supplements, especially in the spring months. The authors raise questions, however, 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) used the CGCM1 and a forage production model, GrassGro Decision Support System (DSS), to estimate the effects of projected climatic 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 that some grazing systems in Saskatchewan may benefit from climate change, if the adaptation options are viable and adopted.

Additional Research on Possible Impacts on Forage and Livestock Production
As noted for crop production, impact assessments have also been made using more general attributes of future climate change. For instance, after modifying levels of CO_2, nitrogen deposition, precipitation, and temperature in experimental plots, Zavaleta and colleagues (2003) concluded that changes to grassland diversity (and therefore grazing availability) may be rapid. The authors replicated plausible future conditions and concluded that while small increases in temperature have no obvious effect, additional CO_2 or nitrogen rapidly decrease species diversity. Their results also illustrate the additive nature of the effects of combined treatments. For example, plots that received both CO_2 and nitrogen exhibited twice the decrease in diversity compared with plots that received just one of the treatments. Indications that soil moisture can increase when the species diversity declines were also noted. Their work confirms the importance of considering many climate change factors simultaneously (Zavaleta et al. 2003).

Future climatic conditions also have direct implications for livestock production (Wolfe, n.d.). Increases in heat stress, for instance, could result in lower weight gains and milk production in cattle/cows, lower conception rates for all livestock types, and substantial losses in poultry production (Adams et al. 1998, cited in Kling et al. 2003). Furthermore, increases in extreme events (e.g., violent storms and flooding) might result in livestock losses (Kling et al. 2003), and high daytime temperatures can reduce total grazing time (Owensby et al. 1996). Water supplies for livestock can be negatively affected by 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 colleagues (2003) review the potential risks for livestock production resulting from the effects of climate change on animal diseases. Table 2.1 summarizes some of the possible disease outcomes for livestock related to altered climatic and weather conditions.

Charron and colleagues (2003) note that alterations in rainfall patterns and temperatures affect the chances of survival and enhancement of insect vectors (ticks, mosquitoes) and associated diseases previously considered exotic or rare (West Nile virus, leishmaniasis). Milder winters can reduce the prevalence of some problems, such as pneumonia in adult cattle. There are, however, greater chances of many more problems 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 influence parasite survival in and on animals, adding to existing parasite loads. Livestock may be also be affected by contaminated runoff in watersheds where heavy rainfall (and/or flooding after drought) flush bacteria and parasites into water systems.

Table 2.1

Potential effects of climate change on vector- and non-vector–borne 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. There may be 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	There may be improved environmental conditions for proliferation of organism. Flooding can increase distribution.
Salmonellosis (*Salmonella* spp.)	Livestock	Water-borne, food-borne	Organism proliferates in warmer conditions. Flooding can increase distribution.
Tuberculosis (*Mycobacterium bovis*)	Livestock	Inhalation, food-borne	Hosts range might expand. Disease agent survives well in cold, damp conditions.
Yersiniosis (*Yersinia enterocolitica, Yersinia pseudotuberculosis*)	Sheep, pigs, goats	Water-borne, food-borne	Stress due to environmental conditions precipitates disease. Flooding can increase distribution.

▶

◄ *Table 2.1*

Disease agent	Animals at risk	Transmission	Effects of climate variability and change
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 (*Orbivirus*)	Sheep, domestic deer	Not applicable	There may be altered geographic distribution of vector species. There may be enhanced vector competence, potential for creating new vector species, increased availability of breeding sites for vectors, increased passive airborne dispersal of vector.

Source: Modified from Charron et al. (2003).

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. 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 subsection.

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. Most estimates of impacts on regional agricultural economies are based on temperature and moisture norms from climate change scenarios. Assessments of climate change traced through agroclimatic conditions and yields are aggregated and suggest that impacts on the North American agricultural economy may be minimal when compared with those expected for less developed nations (Wolfe, n.d.). The IPCC (2001, 56) reports with "high confidence" that for North America, "small to moderate climate change will not imperil food and fibre production," while cautioning that there will likely be wide variation in impacts within the continent. For the US, Reilly and colleagues (2001) used 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 assessed results. Assuming that producers make necessary adaptations, they conclude that climate change in the US will have an overall positive effect on production, with a resulting drop in prices likely leading to challenges for producers (especially those who do not practise adaptation). Adams and colleagues (2003, 131), however, using the RCM (Regional Climate Model), note that positive predictions for climate change impacts are highly questionable given that "assessments based on finer scale climatological information consistently yield a less favourable assessment of the implications of climate change."

Reinsborough (2003) applied a Ricardian analysis for climate change scenarios for Canada, and incorporated projections from the CGCM1. This approach assumes that spatial associations between temperature and other climate norms on the one hand, and agricultural land values on the other, will apply under changed climate, reflecting autonomous adaptations in the agri-food sector. Her work built on US analysis by Mendelsohn and colleagues (1994) that concluded that there may be overall benefits to the agricultural economy with projected climate change. Findings from Mendelsohn and colleagues (1994) were based on the balancing of cropland impacts (which appear to result in 4-5 percent losses) with crop revenue impacts (which appear to result in 1 percent gains). By contrast, Reinsborough (2003) found that gross agricultural revenue under climate change scenarios could improve or decline by 6.4 percent. Such a large margin of error is exacerbated by the difficulties encountered when incorporating realistic adaptation costs (Reinsborough 2003).

Reinsborough's analysis follows other work on the impacts of climate change on Canadian agricultural economy in terms of costs and benefits. Cline (1992) and Kane and colleagues (1992) report negative impacts on the agri-food sector from climate change impacts, while Nordhaus and Boyer (2000) suggest a modest benefit. Reilly (1995) also projects net benefits for Canada as long as assumed adaptation options are pursued and CO_2 fertilization is incorporated in the scenario. Weber and Hauser (2003), using downscaled projections from the CGCM2, concur with Reilly et al. (2003). They base their conclusions on an improved agricultural gross domestic product (GDP) (from increases in land values) in all provinces, suggesting that Reinsborough is too pessimistic.

Much of the research relevant to impacts of climate change 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 earliest assessments of the potential effects of climate change 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 Versatile Soil Moisture Budget (VSMB) for determining crop responses. Their analysis builds on earlier work by Williams and colleagues (1987, cited in Arthur and Abizadeh 1988), who conclude that 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) used the GISS and IISA output to estimate effects on soil erosion, and conclude that there are serious concerns about escalating erosion and salinity in the Prairies connected to potential increases in moisture deficits.

Changes in growing conditions associated with future climatic and weather conditions would have direct effects on the viability of Ontario farming systems. Brklacich and Smit (1992) applied 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. Advantages from longer growing seasons may be offset by reductions in moisture levels, resulting in fluctuating farm income levels and reduced capacity for food production in the province. Brklacich and colleagues (1997b) emphasize producers' adaptation responses to determine possible impacts from altered climatic 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 and colleagues (2003) base their assessment of the effects of climate change on Ontario farming systems on two GCMs, the Parallel Climate Model (PCM) and HadCM3. They note that risks to producers would inevitably result from increasing year-to-year climate variability. This is congruent with the findings of Brklacich and Smit (1992), who suggested greater fluctuations in farm profits resulting from variability in precipitation and extended frost-free seasons. Kling and colleagues (2003) also indicate that small to medium-sized 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 Downscaling 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 extreme events coinciding with hurricane season will be more frequent during fall, and that there will be a substantial increase in days with above-freezing temperatures in winter. The potential increase in growing season length suggests positive outcomes for farming systems, but these may be offset by the negative effects of either too much or too little moisture and extreme events.

Researchers adopting the impact-based approach use climate scenarios to estimate 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 (as well as other factors not captured in the scenarios) will be met depends in large part on producer and institutional adaptive strategies and risk management. These topics are discussed in later chapters.

Beyond the Impact-Based Approach

Agricultural research and agri-food policy have evolved and matured considerably over the past twenty years, primarily in response to the growing awareness that national agricultural economies, including Canada's agri-food sector, are increasingly being influenced by a broader set of forces that originate from within and beyond agricultural sectors. These changes have resulted in several calls for climate/agricultural research to build upon this foundation. Four key themes that would strengthen climate/agricultural research can be identified:

(1) *Broaden the context.* There is a need to move beyond the focus on climate change alone. Agri-food systems are subjected to multiple stressors that are constantly shifting. Thus, to accurately assess the role of climate, climate change assessments must be situated within the complex and dynamic environment in which agriculture operates. Future assessments need to relate not only to future climate scenarios but also to other climatic, environmental, social, economic, and policy conditions, including development pathways (i.e., changes in international trade policies, food preferences, etc.) that are expected to shape the future of agriculture.

(2) *Consideration of multiple spatial and temporal scales.* There is also a need to move beyond the consideration of single spatial and temporal scales in isolation. It is now widely recognized that assessments of climate change on complex agri-food systems must differentiate between fast- and slow-moving parameters and recognize the role of local and broader forces and responses (Clark 1985). For example, climate change models are designed to estimate conditions over several decades, whereas technological advances and economic globalization have been compressing the time associated with major shifts in agricultural production. Research into climate change and agriculture needs to move beyond comparative static assessments to consider dynamic processes of agriculture that reflect decisions from local to international scales.

(3) *Applied concepts of food system vulnerability.* The climate change community has often portrayed vulnerability as an outcome that results when adaptation is not sufficient to overcome negative consequences stemming from climate change (for example, see Ahmad et al. 2001).Vulnerability is primarily used to assess the severity of climate change issues. The natural hazards and famine research communities, however, have long viewed it as a property of socio-economic systems, reflecting inherent susceptibility and adaptive capacity based on determinants such as resource base, institutions, economy, and equity (for examples, see Davis 2002; Wisner et al. 2004). In this context, vulnerability is a reflection of the agricultural system itself, generated by social and economic resources, technology, and environmental constraints. This model of vulnerability as a dynamic, inherent property of agri-food systems provides a basis for understanding what is precipitating the vulnerability (e.g., limited managerial skills or domestic policy that disrupts economic or social safety nets) and offers a way to enhance the policy relevance of climate change/agricultural research. Identifying ways to enhance the adaptive capacity of agricultural systems is key to reducing vulnerability to climate change.

(4) *Enhanced science/policy linkages*. Climate change science has played a crucial role in advancing our collective understanding of how human activities have contributed to global change processes and has provided the foundation for many national and international policy efforts to reduce greenhouse gas emissions as a means to at least reduce the magnitude of global climate change. Efforts to mitigate the cause are without doubt part of the needed response to climate change and, to date, policy responses have focused largely on mitigation. Issues surrounding the adaptation of human systems (including agri-food systems) to climate change have received considerably less attention (internationally and in Canada) for many reasons, including relatively underdeveloped methods for assessing the capacity and likelihood of adaptation options to reduce food system vulnerabilities. The development of more robust and policy-relevant conceptual frameworks, and of analytical tools to estimate inherent food system vulnerabilities and the extent to which various adaptation options might reduce future vulnerabilities and enhance adaptive capacity, would provide a stronger foundation for developing a balanced climate change policy portfolio that addresses both mitigation and adaptation options.

These opportunities to broaden the climate change adaptation research in the agricultural sector are being realized in a number of ways. Several of the more recent scenario-driven studies have considered climate variability, focused on the farm scale, and explored relationships with non-farm forces. Other approaches (context-based and process-based) used in this book to present research on climate change adaptation and Canadian agriculture are introduced in subsequent chapters.

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