ADAPTATION OPTIONS IN AGRICULTURE TO CLIMATE CHANGE: A TYPOLOGY

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Abstract. Adaptation in agriculture to climate change is important for impact and vulnerability assessment and for the development of climate change policy. A wide variety of adaptation options has been proposed as having the potential to reduce vulnerability of agricultural systems to risks related to climate change, often in an *ad hoc* fashion. This paper develops a typology of adaptation to systematically classify and characterize agricultural adaptation options to climate change, drawing primarily on the Canadian situation. In particular, it differentiates adaptation options in agriculture according to the involvement of different agents (producers, industries, governments); the intent, timing and duration of employment of the adaptation; the form and type of the adaptive measure; and the relationship to processes already in place to cope with risks associated with climate stresses. A synthesis of research on adaptation options in Canadian agriculture identifies four main categories: (i) technological developments, (ii) government programs and insurance, (iii) farm production practices, and (iv) farm financial management. In addition to these 'direct adaptations', there are options, particularly information provision, that may stimulate adaptation initiatives. The results reveal that most adaptation options are modifications to on-going farm practices and public policy decision-making processes with respect to a suite of changing climatic (including variability and extremes) and non-climatic conditions (political, economic and social). For progress on implementing adaptations to climate change in agriculture there is a need to better understand the relationship between potential adaptation options and existing farm-level and government decision-making processes and risk management frameworks.

Keywords: adaptation, agriculture, Canada, climate change, policy, response options, typology

1. Introduction

Adaptation is an important component of climate change impact and vulnerability assessment, and is one of the policy options in response to climate change impacts (Fankhauser 1996; Smith and Lenhart 1996; Smit et al. 1999). Indeed, the significant role of adaptation as a policy response by government has been recognized internationally. Article 4.1b of the United Nations Framework Convention on Climate Change (UNFCCC 1992) states that parties are 'committed to formulate and implement national and, where appropriate, regional programs containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change.' The Kyoto Protocol (Article 10) further commits parties to

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promote and facilitate adaptation, and deploy adaptation technologies to address climate change (UNFCCC 1998). Canada, like many other countries, recognizes adaptation as an important component of its climate change response strategy and is exploring adaptation options in several sectors (Canada 2000).

Agriculture is inherently sensitive to climate conditions, and is among the most vulnerable sectors to the risks and impacts of global climate change (Parry and Carter 1989; Reilly 1995). Adaptation is certainly an important component of any policy response to climate change in this sector (Mizina et al. 1999; Reilly and Schimmelpfennig 1999). Studies show that without adaptation, climate change is generally problematic for agricultural production and for agricultural economies and communities; but with adaptation, vulnerability can be reduced and there are numerous opportunities to be realized (Nordhaus 1991; Easterling et al. 1993; Rosenzwieg and Parry 1994; Fankhauser 1996; Smith 1996; Mendelsohn 1998; Wheaton and McIver 1999). In Canadian agriculture, studies have identified climate change risks and have noted needs and opportunities for planned adaptations (Brklacich et al. 1997; Maxwell et al. 1997; Bryant et al. 2000). While adaptation is often considered as a government policy response in agriculture, it also involves decision-making by agri-business and producers at the farm-level (Smit, 1994; Benioff et al. 1996; Adger and Kelly 1999). Adaptations in agriculture vary with respect to the climatic stimuli to which adjustments are made (i.e. various attributes of climate change, including variability and extreme events) and according to the differing farm types and locations, and the economic, political and institutional circumstances in which the climatic stimuli are experienced and management decisions are made (Chiotti and Johnston 1995; Tol et al. 1998; Smit et al. 1999; Bryant et al. 2000).

Many potential agricultural adaptation options have been suggested, representing measures or practices that might be adopted to alleviate expected adverse impacts. They encompass a wide range of forms (technical, financial, managerial), scales (global, regional, local) and participants (governments, industries, farmers) (Smithers and Smit 1997; Skinner et al. 2001). Most of these represent possible or potential or adaptation measures, rather than ones actually adopted. Climate change impact analyses often assume certain adaptations, although the adaptation process itself remains unclear (Chiotti and Johnston 1995; Fankhauser and Tol 1997; Tol et al. 1998; Smit et al. 1999). There is a need to understand what types and forms of adaptation are possible, feasible and likely; who would be involved in their implementation; and what is required to facilitate or encourage their development or adoption. A necessary first step in addressing these concerns is the identification and characterization of adaptation options in agriculture (Brklacich et al. 1997; Bryant et al. 2000; Smit et al. 2000).

The purpose of this paper is to develop a typology of agricultural adaptation options to climate change, focussing on the Canadian case. The paper is a review of current knowledge about adaptation in agriculture from studies of climate impacts, adaptation and vulnerability, and from research on the dynamics of agricultural production and economics. It also incorporates information and insights from the stakeholders who make decisions in the agriculture sector gained through workshops and other communications with representatives from the scientific community, producer organizations, farm groups and government agencies, and individual producers (Smit et al. 2000; Smit 2001). In particular, a national workshop on *Risks and Opportunities for Climate Change for the Agricultural Sector* (Wall 2001) provided information from Canadian agricultural producers and policy makers.

The paper identifies important attributes of climate change for adaptation in agriculture and relates insights about decision-making from several fields of scholarship to agricultural adaptation to climate. A critique of the main dimensions of adaptation provides the basis for the typology of adaptation options in Canadian agriculture. Agricultural adaptation types are differentiated primarily according to the actors involved and the form they take. The adaptation types are also considered according to how they are connected to processes already in place to cope with risks associated with climate and other conditions. The intended contribution of this paper is to systematically characterize the wide variety of types of adaptation to climate change, and to provide some order to these options, in terms of both the forms adaptations can take, and the stakeholders and decision processes involved. The typology has already proven helpful in Canada, both by providing non-trivial and comprehensive examples of adaptations for impact assessment, and by showing the range of adaptations that might be considered in initiatives to improve risk management. However, this paper does not attempt to recommend or prescribe adaptations, nor does it evaluate the relative merit of adaptation options. Such an exercise, building on this typology, has been undertaken (Dolan et al. 2001), demonstrating the considerable additional information requirements. The place-specificity and context-specificity of agricultural adaptations, means that most climate change adaptations are unlikely to be undertaken independently of related risk-management initiatives.

2. Climate Stimuli for Adaptation

In order to understand what adaptation options in Canadian agriculture are possible, it is important to identify the climatic variables to which the adaptations relate, and to consider the role of non-climatic factors that influence the sensitivity of agriculture to climate change. This addresses the question: what is it that agriculture is adapting to? The applicability of adaptation options depends on the nature of the stimuli and associated vulnerability (Wheaton and McIver 1999; Pittock and Jones 2000; Smit et al. 2000).

Traditionally, the impacts of climate change on agriculture have been discussed with respect to current average (or 'normal') growing season conditions and possible future normal conditions (Brklacich and Smit, 1992; Baethgen and Magrin

1995; Brklacich et al. 1997; Mizina et al. 1999). Conventional climate impact scenarios usually focus on the changes in average (mean) temperature and moisture. Some have also considered other climate characteristics such as the growing season length and the timing of frosts, and climate-related factors such as pests and diseases, invariably for an average year sometime in the future (Bryant et al. 2000; Brklacich et al. 2000; Smit et al. 2000).

While most impact studies have considered changed average (mean) climate conditions, usually in a comparative static manner, analyses of agricultural vulnerability indicate that the key attributes of climate change are those related to climatic variability, including the frequency of non-normal conditions (Bryant et al. 2000, Chiotti and Johnston 1995; Smit et al. 1997) For example, the most common problematic climatic conditions identified by a sample of farm operators in Southern Ontario were moisture extremes (drought and excess rain), which accounted for 80% of responses (Smit et al. 1996). Conditions associated with growing season length, heat or solar radiation, the more commonly analyzed variables in climate-scenario-based crop yield studies, were rarely mentioned.

Recent debates focussing on the relationship between climate change stimuli and adaptation in agriculture recognize that climate change includes not only long-term changes in mean conditions, but also a change in the year-to-year variation in growing season conditions, and the frequency and magnitude of extreme weather events (Hulme et al. 1999; Wandel and Smit 2000; IPCC 2001). Understanding that climate change includes climatic variability and extreme events is important in analyses of adaptation. This is particularly so for agriculture, which is generally well adapted to mean or average conditions, but is susceptible to irregular or extreme conditions such as more frequent droughts and deviations from 'normal' growing season conditions (Reilly 1995; Smit et al. 1996; Risbey et al. 1999). Of course, long-term changes in mean conditions, such as cumulative heat and timing of frosts, will have implications for agriculture, but the notable vulnerabilities, and those to which adaptations are most likely to be considered, are those associated with the variability and extremes that are part of climate change. (Chiotti and Johnston 1995; Smithers and Smit 1997; IPCC 2001).

Despite the important influence of climate change, including variability and extremes, adaptation in agriculture does not function and evolve with respect to these climatic stimuli alone. Non-climatic forces such as economic conditions, politics, environment, society and technology, clearly have significant implications for agricultural decision-making, including adaptive decision-making (Bryant 1994; Bryant et al. 2000). The effects of changing commodity prices, trade agreements, resource use rights, and government subsidies and support programs complicate the adaptation process (Brklacich et al. 2000; Smit et al. 1996). Adjustments in agriculture are made routinely in response to non-climatic conditions, especially the market, as much as to changing climate conditions. Non-climatic conditions may amplify or exacerbate climate-related risks, or they may dampen, counteract or overwhelm the climatic effects. Adaptive decisions in agriculture are made in light of the joint effects of climatic and non-climatic conditions and for commercial farmers these effects are eventually experienced in an economic manner.

3. Analytical Approaches to Adaptation in Agriculture

Insights into agricultural adaptation to climatic change come from a variety of research approaches, which consider various scales (plant, plot, field, farm, region, sector, nation and international) and employ several different perspectives (Smithers and Smit 1997; Bryant et al. 2000; Skinner et al. 2001). These approaches include research on climate change impacts; natural hazards; agrarian political economy; innovation adoption; agricultural systems and farm decision-making; risk management; and agricultural vulnerability and adaptation. In the following sections, these bodies of scholarship are summarized with respect to their main perspectives and approaches to adaptation, and their contribution to our understanding of adaptation in agriculture.

3.1. Conventional Climatic Change Impact Assessment

Early climate change impact assessments did not consider adaptation. Yet, with the potential to modify adverse impacts of climate change, adaptation is important to the estimation of climate change impacts (Reilly 1995). Although agriculture is one of the most widely studied sectors with respect to the impacts of climate change (IPCC 1996; 2001), adaptation in agriculture has still received little explicit consideration in the impact assessment literature (Chiotti and Johnston 1995). This is partly because many studies do not go beyond estimating crop yield responses, essentially ignoring human decision-making in the agrifood sector. Conventional, scenario-based studies providing predictions of potential impacts in agriculture have addressed adaptation mostly by making assumptions about human responses (Easterling et al. 1993; Rosenzweig and Parry 1994). Early (first-generation) impact assessment models provided estimates of the overall agricultural impacts or damages of climate change based on the assumption that no adaptations would occur (Rosenzweig 1985; Smit et al. 1989). Later (second-generation) impact assessment models arbitrarily assigned adaptations to climate change, assuming adaptive responses on the part of agricultural producers or the system as a whole with respect to changes in average temperature and moisture conditions (Adams et al. 1995; Mendelsohn et al. 1994; Easterling et al. 1992). More recently, impact assessments have recognized the importance of farm-level decision-making in the adaptation process, particularly when climatic extremes are considered, and studies have begun to focus on the role of human agency by researching farmer perceptions and risk management choices (Brklacich et al. 1997; Chiotti et al. 1997; Smit et al. 1997).

Certainly the earlier focus on the potential biophysical impacts of climate change scenarios on agricultural production (i.e. plant growth and crop yields) has shifted to include considerations of possible adaptations by producers (Bryant et al. 2000). However, there is still little analysis in the impact assessment literature of actual farm level decision-making in agriculture or of how such decisions relate to public policies.

3.2. Natural hazards

Recognition that the pertinent features of climate change for most sectors are those associated with year-to-year variability and the frequency and magnitude of extreme climatic events has prompted consideration of adaptation in light of natural hazards (Smit et al. 1996; Smithers and Smit 1997). Natural hazards research is a long-established scholarly field that explores the interactions of humans and the environment by focussing on the impacts of, and human responses to, extreme events (Burton et al. 1993). Much attention has been directed to the identification and characterization of human adjustments to calamitous (extreme) events. Characteristics of the system being impacted and the perceptions of hazard risk by those impacted are noted as important in understanding human coping strategies and adjustments (Burton et al. 1993).

Climate change studies of agriculture address adaptation as an adjustment to the risks associated with changes in averages and, more recently, with recurring extreme events (Bryant et al. 2000). These analyses can be informed by natural hazards research, especially by raising the questions of how farmers perceive the risks associated with climate change (Brklacich et al. 1997; Chiotti et al. 1997; Smit et al. 1996), and by recognizing that adaptation is directly related to the perception of risks and involves conscious (planned) decision-making.

3.3. Agrarian political economy

Research focussing on rural and agricultural change emphasizes the important role of institutions and other macro-level forces in the agri-food sector (Bryant and Johnston 1992; Ilbery et al. 1997). Studies have addressed changes in agriculture, including adaptation as a decision-making process affected by political and economic variables (Blaikie and Brookfield 1987). This literature recognizes that adaptation does not simply occur independently at the field or farm level, but it is a process greatly influenced by broader economic, political and social forces. In addition, policy initiatives by governments represent adaptations for the sector as a whole. The role of government policies, institutional arrangements, and macro-level social and economic conditions is increasingly recognized in adaptation studies (Smit 1994; Chiotti and Johnston 1995; Mizina et al. 1999).

3.4. Innovation adoption

The adoption of technological innovations is one of the most frequently advocated strategies for adaptation in agriculture to climate change (Houghton et al. 1990;

Rosenberg 1992). Innovation adoption research provides insights into the decision-making process by which adaptations are implemented by producers and diffused among farming communities (Jones 1967). Studies in this field focus on the characteristics of producers that influence their decisions about adaptation measures. Factors such as decision-maker (producer) attitudes, values, motivations, and perceptions of risk distinguish between producers who are 'innovators' and those who are 'laggards' with respect to the adoption of particular innovations (Rogers 1983). Much attention also has been directed towards the attributes of specific innovations that lead to their adoption. Factors such as profitability, complexity and compatibility distinguish between innovations that are quickly up-taken and those that are not widely employed (Guerin and Guerin 1994).

Innovation adoption research recognizes that adaptation is a multi-faceted decision-making process, is a function of the personal and situational circumstances of the decision-maker and the characteristics of the innovation under consideration, that occurs within a context of changing economic, social, political and biophysical conditions (Rogers and Shoemaker 1971; Ilbery 1985; Chamala 1987). This perspective informs an understanding of the processes by which adaptation options are implemented and their likelihood of adoption.

3.5. Agricultural systems and farm decision-making

Agricultural systems research has provided much useful information on the nature and dynamics of agricultural production systems and their responses to a myriad of climatic and non-climatic stimuli. It characterizes agriculture as a complex system, within which changes are driven by the joint effects of economic, environmental, political and social forces (Olmstead 1970; Bryant and Johnston 1992). This approach emphasizes the interconnections among the various levels within the agriculture system (i.e. field, farm, community, region and nation) and can describe change at aggregate scales and individual farm scales (Cocklin et al. 1997). Models have been developed in this field to assess the economic impacts of climate-related changes in agriculture based on simulations of farm decision-making at the regional (aggregate) scale (Klein et al. 1989) and estimates of changes in profitability at the farm-level (Arthur and Van Kooten 1992). Studies have shown that decisions involving changes in agriculture are made at different levels that are interrelated, and as a result, patterns of agricultural activity, including adaptation, are the product of many individual decisions (i.e. by government, agri-business and individual producers) (Chiotti et al. 1997; Smithers and Smit 1997).

Farm decision-making is seen as an on-going process, whereby producers are continually making short-term and long-term decisions to manage risks emanating from a variety of climatic and non-climatic sources (Ilbery 1985). In this sense, adaptation is the result of individual decisions influenced by forces internal to the farm household (i.e. risk of income loss, environmental perception), and the external forces that affect the agricultural system at large (i.e. macro-economic policy, institutional frameworks) (Chiotti and Johnston 1995).

3.6. Risk management

Climate change, including variability and extremes, is a pervasive source of risk to agriculture. However, little attention has been directed towards farm-level risk management strategies in light of the uncertainty associated with the changing and variable climatic conditions (Smit et al. 2000). Risk management research recognizes that decisions in agriculture involve both risk assessment and specific actions taken to reduce, hedge, transfer or mitigate risk (Wandel and Smit 2000). Within this field, adaptation is often considered a response to financial risk in agriculture (climatic or non-climatic) (Barry and Baker 1984). Many studies have identified sources and types of farm-level risk due to climate change (Fleisher 1990; Anderson 1997; Turvey 2000) and considered how these risks might be managed through adaptation (Easterling 1996; Chiotti et al. 1997). This literature provides valuable insights into agricultural decision-making with respect to adaptation in light of the uncertainties associated with climate change, especially those associated with variability and extremes.

3.7. Agricultural vulnerability and adaptation

The vulnerability approach to climate change recognizes that there are pertinent climatic attributes to which agricultural systems are sensitive, and that these attributes can be used as a platform for analyzing the implications of climate change (Kates 1985; Carter et al. 1994; Downing 1991). Vulnerability research identifies the climatic attributes relevant to specific agricultural systems (Parry 1985; Swart and Vellinga 1994), examines how these attributes are experienced through the variability and extremes associated with climate change (Burton 1997), and considers adaptation strategies in light of these climatic stimuli and the other conditions that influence decision-making (Smit et al. 1996; Kelly and Adger 2000). The vulnerability approach can identify differing sensitivities of specific agricultural systems, as a target for adaptation initiatives, and can indicate the types of adaptation that have been attempted with respect to climatic stimuli. This approach can provide insights into the conditions under which adaptive decision might be made.

From the bodies of literature summarized above, several insights about agricultural adaptation are apparent. Adaptations to climatic conditions are quite common in the agricultural sector. The sector is particularly sensitive to climatic variability and extreme events. Adaptive decisions are not likely to be made in light of (or in response to) climatic conditions or risks alone, because such decisions are invariably driven by joint effects of multiple forces. Such decisions are likely to be made as part of on-going risk management. Adaptations can occur at several scales from an individual farm to a national public policy, involving interrelated but different actors. At the local or regional scales, adaptations and their likelihood of adoption will vary depending upon local circumstances. These insights provide an important backdrop for understanding the various dimensions of agricultural adaptation to climate change.

4. Characteristics of Adaptations

There is a huge number and variety of measures or actions that could be undertaken in agriculture to adapt to climate change (Smit 1993; Kelly and Granich 1995; Reilly 1995; Brklacich et al. 1997; Reilly and Schimmelpfennig 1999). There also exist numerous characteristics by which adaptations can be distinguished, and which could serve as bases for a typology of agricultural adaptations (Burton et al. 1993; Stakhiv 1993; Carter et al. 1994; Bijlsma et al. 1996; Smithers and Smit 1997). Among the distinguishing characteristics of adaptation are intent and purposefulness, timing and duration; scale and responsibility; and form.

4.1. Intent and Purposefulness

Intent and purposefulness differentiate between adaptations that are undertaken spontaneously, or autonomously, as a regular part of on-going management from those that are consciously and specifically planned in light of a climate-related risks (Carter et al. 1994; Bryant et al. 2000; Smit et al. 2000). Within socio-economic systems, public sector adaptations are usually consciously planned strategies, such as investments in government programs, but private sector and individual adaptations can be autonomous, planned or a combination of the two. For example, the decisions of a producer who, over many years, gradually phases out one crop variety in favour of another that seems to do better in the climatic conditions, might be considered spontaneous and autonomous, but they are also consciously undertaken.

4.2. Timing and Duration

Timing of adaptation differentiates responses that are anticipatory (proactive), concurrent (during), or responsive (reactive). While logical in principle, this distinction is less clearcut in practice. For example, a producer who has experienced several droughts over recent years, and expects drought frequency to remain similar or increase in the future, may adjust certain production practices or financial arrangements to manage drought risks. The timing distinction is not helpful here, as this is both a reactive and proactive adaptation.

Duration of adaptation distinguishes responses according to the time frame over which they apply, such as tactical (shorter-term) versus strategic (longer-term) (Stakhiv 1993; Smit et al. 1996). In agriculture, tactical adaptations might include adjustments made within a season, that involve dealing with a climatic condition, such as drought, in the short term. Tactical adaptations might include selling of livestock, purchasing feed, plowing down a crop or taking out a bank loan. Strategic adaptations refer to structural changes in the farm operation or changes in enterprises or management that would apply for a subsequent season, or a longer term. Thus, strategic adaptations might include changes in land use, enterprise mix, crop type or use of insurance.

4.3. Scale and Responsibility

Adaptations can be distinguished according to the scale at which they occur and the agent responsible for their development and employment. In agriculture, adaptations occur at a variety of spatial scales, including plant, plot, field, farm, region and nation (Smithers and Smit 1997). At the same time, responsibility can be differentiated among the various actors that undertake or facilitate adaptations in agriculture including individual producers (farmers), agri-business (private industries), and governments (public agencies) (Smit et al. 2000). However, most discussions of adaptation do not distinguish the roles of different decision-makers. For example, a commonly espoused adaptation in agriculture is the use of crop development for changed climatic conditions. Such an adaptation would likely involve government agencies (encouraging this focus in breeding research), corporations (developing and marketing new crop varieties), and also producers (selecting and growing new crops). Any realistic assessment of adaptation options needs to systematically consider the roles of the various stakeholders.

4.4. Form

Adaptation in agriculture occurs via a variety of processes and can take many different forms at any given scale or with respect to any given stakeholder. Distinctions among adaptations based on form have been suggested by, among others, Burton et al. (1993), Carter et al. (1994) and Smithers and Smit (1997). These studies consider adaptations according to their administrative, financial, institutional, legal, managerial, organizational, political, practical, structural, and technological characteristics. For example, Bryant et al. (2000) identify forms of adaptation at the farm-level, including modification of resource management, purchasing crop insurance, and diversification. They also identify different forms of policy level adaptations including aid for research and development, incentive strategies and infrastructure measures. Differentiating responses to climate change according to form provides a useful framework for understanding adaptation in agriculture.

5. Types of Adaptation Options in Agriculture

This section identifies types of agricultural adaptation to climate change, and gives examples of the types. While the typology is rather generic, the examples are mostly drawn from Canadian literature and experience. In particular, valuable information was gained from workshops and other communications with producer organization representatives, farm groups, government agency representatives, and individual producers (see Smit 2001; Smit et al. 2000; Wall 2001, and Acknowledgements).

This paper takes adaptation to refer to 'adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts' (Smit et al. 2000, p. 6). As a result, the types of adaptations included here are activities that represent changes in some attribute of the agricultural system (the agriculture sector or farms within it) directly related to reducing vulnerability to climate change.

It is common in reviews of adaptation options to include activities, such as the provision of information on climate change and potential impacts, that may improve general awareness or prompt consideration of adaptations, but that, in themselves, are not direct changes in the agriculture sector or farms within it (Bryant et al. 2000). Certainly, the dissemination of information (on climate change, possible impacts and vulnerabilities, potential adaptation options, etc.) is something governments can do to promote adaptations, and it may be a necessary precursor to adoption of adaptation measures. This is especially important given insights from the natural hazards and innovation adoption literature regarding the role of perception in the adaptation process. However, we consider information provision, dissemination and training as important parts of the means by which adaptation might be encouraged rather than as specific agricultural adaptations in their own right.

Agricultural adaptation options are grouped according to four main categories that are not mutually exclusive: (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management. The typology is based on the scale at which adaptations are undertaken and at which the stakeholders are involved. The first two categories are principally the responsibility of public agencies and agri-business, and adaptations included in these categories might be thought of as system-wide or macro-scale. Categories 3 and 4 mainly involve farm-level decision-making by producers. Of course, the categories are often interdependent. For example, an adaptation technology developed by government and the private sector (type 1), might be adopted to modify farm production practices (type 3). As another example, a producer may buy more crop insurance (type 4), when this insurance is supplied or subsidized by government (type 2).

Within each category specific examples are considered in light of the distinctions discussed earlier and farm decision-making in general. The main types of adaptations are summarized in Table I with examples in each category.

TABLE I

Types and selected examples of adaptation options in Canadian agriculture.

TECHNOLOGICAL DEVELOPMENTS

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.

GOVERNMENT PROGRAMS AND INSURANCE

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.

FARM PRODUCTION PRACTICES

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.

TABLE I

Continued.

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.

FARM FINANCIAL MANAGEMENT

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.

5.1. Technological Developments

Technological adaptations are developed through research programs undertaken or sponsored by federal and provincial governments, and through research and development programs of private sector industries. As summarized in Table I, technological adaptation options have been developed or proposed in crop development (to increase their tolerance); weather and climate information systems (to provide forecasts); and resource management (to deal with of climate-related risks).

The development of new crop varieties including types, cultivars and hybrids, has the potential to provide crop choices better suited to temperature, moisture and other conditions associated with climate change. This involves the development of plant varieties that are more tolerant to such climatic conditions as heat or drought through conventional breeding, cloning and genetic engineering (Joseph and Keddie 1981; Major et al. 1991; Smithers and Blay-Palmer 2001). In Canada, most crop development is undertaken in the private sector. In soybeans, for example, five new varieties were developed between 1967 and 1970, all by the public sector. In 1998, 132 varieties were developed, of which 119 (90%) were listed by private sector (Smithers and Blay-Palmer 2001). Although crop development is often proposed as an adaptation option, little attention has been directed towards increasing resilience to particular climate conditions.

Most crop development, whatever its focus, is undertaken in light of prevailing climatic conditions, and there have been remarkable achievements in the development of crops suited to particular climatic norms (Duvick 1992; Slater 1994). There is little evidence that the crop development community (public and private) has targeted 'robustness' to climatic variations (also known as stability and resilience) in its programs (Smithers and Blay-Palmer 2000). It has been suggested (Tollenaar et al. 1994; Tollenaar and Wu 1999) that, in the case of corn, there has been improvement in this robustness, perhaps a serendipitous development related to the nature of breeding selection. On the other hand, van Herk (2001) has noted that not only is climatic variability not a target for crop breeding (although it could be), but also that an anomalous climatic season (e.g. drought) is seen as an inconvenience in field testing, with its results discarded, rather than as an opportunity to develop and retain the robustness features of the crop variety that does well under such anomalous conditions. Furthermore, there already exist a very wide range of crops and varieties, with differing climatic requirements, yet farmers still have to make management choices when selecting among these with only probabilistic knowledge of the growing season conditions (Smit et al. 1997).

Another type of technological advance is the development of information systems capable of forecasting weather and climate conditions associated with climate change. Weather predictions over days or weeks have relevance to the timing of operations such as planting, spraying or harvesting. Seasonal forecasts, such as estimates of the likelihood of conditions associated with El Niño – Southern Oscillation phenomena, have the potential to aid risk assessment and production decisions over several months. Information on longer-term climate change can inform farmers about future norms and variability, and the probability of extreme events. In these ways, weather and climate information systems can assist farm-level adaptation. Farmers may use this information with respect to the timing of operations (i.e. planting and harvesting) (Carlson 1989; Wilks 1992), the choice of production activities (i.e. crop varieties) (Murphy 1994), the type of production (i.e. irrigation or dry-land agriculture) (Reilly 1995), and financial management activities (i.e. use of crop insurance and water rights) (Luo et al. 1994). While seasonal forecasts have potential to aid production decisions (Murphy 1994), studies of producer perceptions and decision-making show that their reliability would have to be greatly improved before they influence producer risk management choices (Brklacich et al. 1997).

The development of technological innovations in resource management also has the potential to address climate-related stimuli. Broad-scale water resource management innovations address the risk of water (moisture) deficiencies or surpluses associated with shifting precipitation patterns and the probability of more frequent floods and/or droughts. At a regional scale, involving public agencies, these innovations include the development or modification of irrigation systems, water transfers, water diversions, and desalinization technologies (Smit 1993; Easterling 1996; de Loë et al. 1999). Farm-level resource management innovations have also been proposed. These adaptations include mechanical innovations such as the development of integrated drainage systems, land contouring, reservoirs and recharge areas, and alternative tillage systems (Rosenberg 1981; Dumanski et al. 1986; Spaling 1995; Easterling 1996). Water resource management innovations assume adequate supplies of water and are often constrained by prevailing economic and institutional arrangements. The lead responsibility for developing technological adaptations tends to be governments and agri-business; whereas the employment or adoption of these technologies is a farm-level decision. As Crosson and Rosenberg (1989, p. 128) note when acknowledging that research will yield many new technologies for expanding food production while preserving land, water and genetic diversity: 'The real trick will be getting farmers to use them'.

5.2. Government programs and insurance

Government programs and insurance are institutional responses to the economic risks associated with climate change and have the potential to influence farm-level risk management strategies. These include government *agricultural subsidy and support* (to decrease the risk of climate-related income loss, and spread exposure to climate-related risks publicly); *private insurance* (to decrease the risk of climate-related income loss, and spread exposure to climate-related risks privately); and *resource management programs* (to influence resource management in light of changing climate conditions).

Agricultural subsidy and support programs involve modifications to and investment in established and *ad hoc* government programs. *Ad hoc* programs provide compensation for disaster-related income loss independent of the support provided by established crop insurance, income stabilization and farm production subsidy, support and incentive programs (Schmitz et al. 1994; Smit 1994; Smithers 1998). All of these programs greatly influence farm-level production and management strategies by transferring risk in agriculture (Smit el al. 2000). Modifications to the terms of reference for crop insurance or other farm production subsidies, supports and incentives have the potential to encourage or discourage changes in farm-level production and management by spreading exposure to climate-related risks (Ye and Yeh 1995; Wang et al. 1998; Turvey 2000). Changes to government investment in income stabilization and disaster relief have the potential to alter the funds available to farmers to reduce the risk of income loss as a result of increased incidence, severity and duration of droughts, floods and other climate related-events (Romain and Calkins 1996; Changnon et al. 1997; Love et al. 1997). The success of agricultural subsidy and support programs has been difficult to determine as government programs seldom address climate-related risks independently of other risks to agriculture (Van Kooten and Arthur 1997).

An analysis of the use of subsidized crop insurance relative to other risk management strategies by soybean producers in southern Ontario, Canada, (Smithers 1998) showed that insured farmers tended to implement other risk management strategies, such as variety rotation and planting schedule adjustment, just as frequently as uninsured farmers. However, use of crop insurance was associated with less diversification and lower levels of off-farm income, both which may be seen as adaptive measures. There was also evidence that farmers were substituting the broad income protection scheme (Net Income Stabilization Account – NISA) for the more specific crop insurance, although a majority used both. NISA is a voluntary, subsidized, self-directed savings program, from which producers may draw when their net income falls below a threshold value, regardless of the source of the income loss. Smithers (1998) shows that from the farmers' perspective, crop insurance and NISA are fall-back measures, to compensate for loss after other adaptive management strategies fail.

The development of private insurance represents an adaptation to climate-related risks that is primarily the responsibility of the financial services sector, which, in turn, is usually influenced by government programs. This involves the development of insurance schemes by private companies to address crop and property damage from such climate-related hazards as droughts, floods and other climate-related events. Although this type of adaptation has the potential to reduce vulnerability at the farm-level, its implementation in Canada is limited by the availability of existing government subsidized crop insurance and support programs to farmers (Boddis 1994) and the increasing liabilities related to climate change experienced by the Canadian insurance industry (MacDonald 2000).

Resource management programs involve the development of government policies and programs that encourage or discourage changes in land use, water use and management practices. This type of adaptation includes the development of land use regulations (Chiotti and Johnston 1995), water use permits (Easterling 1996) and 'best management' practices (Agriculture and Agri-Food Canada 1995). Resource management programs also have the potential to address broad-scale changes such as northward shifts in pest infestations (Smit 1993) and boreal forest patterns (Van Kooten 1995). Implementation of these programs will require an assessment of existing institutional and economic arrangements and could require changes to existing legislation (Chiotti et al. 1997; de Loë et al. 1999). These policy instruments of governments represent adaptations at an aggregate scale and also influence farm-level adaptation decision-making.

5.3. Farm production practices

Farm production practices involve changes in farm operational practices, which may be stimulated or informed by government programs or industry initiatives. Farm production adaptations include farm-level decisions with respect to farm production, land use, land topography, irrigation, and the timing of operations (Table I).

Changing farm production activities have the potential to reduce exposure to climate-related risks and increase the flexibility of farm production to changing climatic conditions. Production adaptations could include the diversification of crop and livestock varieties, and changes to the intensity of production. Altering crop and livestock varieties, including the substitution of plant types, cultivars and hybrids, and animal breeds designed for higher drought or heat tolerance, has the potential to increase farm efficiency in light of changing temperature and moisture stresses (Smit et al. 1996; Chiotti et al. 1997). Altering the intensity of chemical (i.e. fertilizers and pesticides), capital and labour inputs has the potential to reduce the risks in farm production in light of climate change (Brklacich et al. 1997, 2000; Hucq et al. 2000).

There have been few analyses of production decision-making in light of climate change conditions. Smithers and Smit (1997) analyzed variations in climate, crop yields, technology, cropping area and crop insurance, over 3 decades in southern Ontario. This aggregate analysis found that there was some change in the area planted in corn and soybeans after extreme years, but this was less apparent as crop insurance was more widely used. Smit et al. (1996) studied 120 farmers in southern Ontario, finding that producers routinely changed aspects of their operations, in response to various stimuli. In response to dry years, two thirds did nothing, 13% made tactical changes (e.g. reducing inputs, buying-in feed or selling livestock), and 21% made strategic changes (e.g. crop type, livestock type, land use or tillage practices).

Smit et al. (1997) found that grain corn farmers in Ontario adjusted to their experience with growing season conditions in their selection of corn crop varieties for the subsequent year. Brklacich et al. (2000) found that about two thirds of livestock farmers and one third of diversified farmers in eastern Ontario had made adaptations to climatic change between 1977 and 1997. Whether to reduce production risks or to increase productivity levels, the most common adaptations were switching crop types and altering harvest dates. These studies also show that decisions about changes in farm production practices are unlikely to be made in light of climate change risks separately from the risks associated with other economic, technological, social and political forces.

Changing land use practices involves altering the location or nature of crop and livestock production. Rotating or shifting production between crops and livestock, and shifting production away from marginal areas has the potential to reduce soil erosion and improve moisture and nutrient retention. (Delcourt and Van Kooten

1995) The conservation of moisture and nutrients in light of more frequent droughts can also be improved through the use of alternative fallow and tillage practices (Chiotti et al. 1997; Hucq et al. 2000).

Changing land topography involves land contouring and terracing, and the construction of diversions, reservoirs, and water storage and recharge areas (Smit 1993; Easterling 1996). This type of adaptation reduces farm production vulnerability by decreasing runoff and erosion, improves the retention of moisture and nutrients, and improves water uptake (de Loë et al. 1999).

Implementing irrigation practices involves the introduction or the enhancement of specific water management innovations including centre pivot irrigation, dormant season irrigation, drip irrigation, gravity irrigation, pipe irrigation and sprinkler irrigation (Smit 1993). Irrigation practices also involve changing the scheduling of existing systems (Chiotti and Johnston 1995). This type of adaptation can increase moisture retention in light of decreasing precipitation and increasing evaporation, and more frequent droughts. Irrigation practices could improve farm productivity and enable diversification of production in light of climate-related changes (i.e. switching to crops that would otherwise not thrive in dryland agriculture) (Brklacich et al. 1997; Klassen and Gilpen 1998).

Changing the timing of operations involves production decisions, such as planting, spraying and harvesting, to take advantage of the changing duration of growing seasons and associated changes in temperature and moisture. This type of adaptation includes the scheduling of crop and livestock production activities such as chemical inputs (Chiotti and Johnston 1995), grazing (Chiotti et al. 1997), irrigation (de Loë et al. 1999), harvesting, mulches, planting, seeding, and tillage (Smit 1993; Brklacich et al. 2000). Changing the timing of these farm practices has the potential to maximize farm productivity during the growing season and to avoid heat stresses and moisture deficiencies.

5.4. Farm Financial Management

Farm financial adaptation options are farm-level responses using farm income strategies (both government supported and private) to reduce the risk of climate-related income loss. Government agricultural support and incentive programs greatly influence farm financial management decisions. Farm financial adaptations involve decisions with respect to crop insurance, crop shares and futures, income stabilization programs, and household income (Table I).

Crop insurance reduces income loss as a result of reduced crop yields from droughts, floods and other climate-related events, and in the case of subsidized programs (as in Canada) this spreads exposure to climate-related risks publicly (Smit 1993; de Loë et al. 1999). Purchasing insurance entails financial decision-making aimed at stabilizing income from crop production in light of climate change risks. This type of adaptation includes participation in established federal and provincial subsidized crop insurance programs (Turvey 2000). At the sector scale, publicly supported crop insurance and disaster relief programs represent an important type of adaptation in countries like Canada. The 2001 drought in Ontario resulted in a record $258 million crop insurance payout. Not only does this represent a type of adaptation to climate variability employed by many producers, but it may influence the propensity to adopt other types of adaptation. However, Smithers' (1998) study of soybean growers in Ontario showed little evidence of this 'moral hazard'. Farmers who had purchased crop insurance tended to employ other risk management strategies (e.g. changes in variety, rotation and planting schedule) just as much as uninsured producers. More specialized farms and those with less off-farm income tended to rely more heavily on crop insurance.

Investment in crop shares and futures has also been proposed to spread exposure to climate-related risks and reduce vulnerability to income loss (Mahul and Vermersch 2000). This adaptation option involves the use of securities, shares and other financial options developed by government and industry, including banks, as an alternative financial management strategy to crop insurance (Turvey and Baker 1990; McCulloch et al. 1994; Chiotti et al. 1997).

Participation in income stabilization programs also has the potential to spread exposure to risk borne by farmers and reduce their vulnerability to climate change. Many Canadian farmers already participate in established federal and provincial income stabilization programs, such as the Dairy Subsidization Program, Agricultural Income Disaster Assistance (AIDA) and the Net Income Stabilization Account (NISA) (Agriculture and Agri-Food Canada 2001). Although the use of income stabilization programs is recognized as a potential climatic adaptation (Schweger and Hooey 1991), it is unlikely to be considered independently of other political and economic influences.

Household income strategies have long been important adaptation options in Canadian agriculture. Such financial decisions may also represent a means of dealing with economic losses or risks associated with climate change (Wandel and Smit 2000). Diversification of income sources has been identified as an adaptation option, including off-farm employment and pluriactivity, which has the potential to reduce vulnerability to climate-related income loss (Brklacich et al. 1997; Smithers and Smit 1997; de Loë et al. 1999). As with many adaptations, diversification of household incomes is unlikely to be undertaken directly in response to climatic perturbations alone (Bradshaw et al. 2001).

6. Adaptation Processes

The typology illustrates the myriad of agricultural adaptation options available to governments, industries and individual farmers to reduce vulnerability to climate change risks. There are many kinds of technological, public policy and farm management options with potential to moderate problematic climate change effects or to realize opportunities, reinforcing the view that the agricultural sector is very adaptable. Yet the process of adaptation in agriculture itself is rarely researched. There has been very little research on the likelihood that such adaptation measures would actually be adopted, or on the conditions under which such adaptations might be employed in the agri-food sector. Our limited knowledge of actual adaptation decision making (corroborated by findings from research on innovation adoption and agricultural risk management) indicates, among other things, that (1) there are distinctive (although inter-related) roles in adaptation for individual farm operators, agri-business (industry), and governments; (2) decisions to adopt or modify measures or practices are rarely made relative to one risk alone, but in light of the mix of conditions and risks (climate, trade, prices, social norms, etc.) that influence decision-making; and (3) decisions to adopt or modify measures or practices are usually made not in a 'once-off' manner, but in a dynamic, on-going 'trial-by-error' process.

Adaptation in agriculture involves various 'stakeholders' with different, yet often inter-related points of view. In order to evaluate and promote practically the adoption of adaptations such as the development of new crops or irrigation, it is necessary to recognize which players are involved and what their roles are with respect to adaptation. As illustrated in the typology, significant distinctions exist between adaptation options that are employed by private decision-makers, including industry and individual producers (farmers), and public decision-makers (government and public agencies). However, private and public adaptation options are not necessarily independent of each another, and often have inter-related roles in the adaptation process. To illustrate, while it is the farmer's decision to buy water from irrigation scheme and to invest in the on-farm equipment to irrigate, this option is dependent on some public agency establishing the regional infrastructure and managing the allocation system.

Many public programs and policies such as the development of crop varieties, resource management innovations and crop insurance are designed to directly influence individual behaviour with respect to adaptation. Indeed, the sharing of costs and benefits between government, industry and farmers is a key concern in understanding adaptation in agriculture, and influences the likelihood of adaptation options actually being implemented. The removal of publicity funded hazard insurance and compensation in New Zealand's agriculture in the late 1980s stimulated numerous adaptations including abandonment of climate-sensitive crops in risk-prone areas, reduction in farming intensity to provide flexibility, diversification of products and inputs, spatial diversification, development and use of more drought-resistant grasses, and expansion of private agricultural insurance (Smit 1994).

If governments seek ways to encourage adaptation (to reduce losses or realize opportunities), they need to be aware of how government initiatives with respect to climate adaptation relate to producer decisions. For example, there is increasing interest in evaluating the relative merit of alternative adaptation options, so that the better ones might be encouraged (Smith and Lenhart 1996; Klein and Tol 1997;

Mizina et al. 1999). Such evaluations are conventionally based on such criteria as effectiveness, economic efficiency, implementability, flexibility and so on. Both the evaluation criteria themselves and the performance on criteria may differ greatly depending upon whether the evaluation was taken from the point of view of a government or a producer (Dolan et al. 2001). A highly subsidized insurance program may be very cost-effective for farmers but not at all cost effective for the government.

Understanding the relationships between adaptation options and the existing processes in place to ameliorate the impacts of climate change is a key component of any evaluation of adaptation options and of analyses of the likelihood of adaptation options actually being implemented. Ultimately, adaptations in agriculture occur via decisions of producers (to employ a technology, to choose a crop, to change a practice, to alter timing, to modify inputs, to buy insurance, to enroll in a stabilization program, etc.). These decisions are made in the context of prevailing economic conditions, institutional and regulatory arrangements, and of existing technology, policy, financial systems, and social norms (Bryant et al. 2000). Adaptation processes are articulated through the institutional and regulatory mechanisms of prevailing agricultural, economic, financial, management, political and technological systems (Bryant 1994). The mechanisms through which adaptation occurs are widespread and include public research and extension programs, resource management legislation and regulations, agricultural support programs, and economic policies (Titus 1990; Carter 1996; Smith 1996). Adaptation options in agriculture are adopted relative to these mechanisms, which have the potential to modify the significance of climate-related stresses experienced in agriculture and are important constraints in the farm decision-making process.

The connections between adaptation options and existing adaptation processes and mechanisms involve primarily relationships between farm production practices and financial management, and public sector decision-making processes. For example, the adoption of irrigation as a farm production practice adaptation may be constrained by the existence of water management regulations such as the legislation of water use rights (de Loë et al. 1999). Government research and extension programs promoting resource management innovations may also influence the adoption of farm production practice options through education and incentives (Hucq et al. 2000). In terms of farm financial management, agricultural support programs and macro-economic policies often influence the adoption of adaptation options (Lewandrowski and Brazee 1993). Decisions regarding the diversification of household income in light of climate change may be influenced by government policies encouraging a general move away from agricultural production in some areas (Smit 1993).

Most adaptation options are not discrete technical measures likely to be undertaken specifically with respect to climate change. Rather, they are modifications to on-going farm practices and public level policies with respect not only to climate change but also to climatic variability and extremes, and other political, economic and social conditions. Agricultural decision-making with respect to adaptation to climate change is not likely to be considered as separate from other agricultural decisions. Nor is agricultural adaptation likely to be considered as independent of non-climatic stimuli (such as economic conditions, institutional arrangements, social norms and politics). At both the producer (farm) and government levels, decisions are made continuously, in an on-going, 'incremental' fashion, in light of multiple stimuli and conditions.

For example, the decision to diversify farm production or household income is not considered with respect to climate risks alone. Market risks, personal preferences, and capital and labour costs associated with changing production or enterprises are likely to overshadow the climatic stimuli for adaptation. Similarly, government decisions regarding irrigation, crop insurance, subsidy and support programs, and resource management are made with respect to various economic, social, environmental and political conditions of which climatic conditions may play a very small role.

In identifying and evaluating which adaptations are attractive (and therefore likely to be adopted), consideration must be given to how they relate to on-going decision making processes, constraints, stimuli and decision criteria. Although the typology provides various examples of these relationships, further consideration of the connection between adaptation processes and decision mechanisms is necessary to usefully evaluate options, to fully address the likelihood that adaptation options will be implemented, and to identify the conditions and constraints under which they might be employed.

7. Conclusions

The international literature on climate change impacts and vulnerability in the agricultural sector is increasingly recognizing the important role of adaptation. In assessments of the 'costs' of climate change, analysts attempt to estimate adaptations that are likely to occur. In programs to reduce vulnerability, practitioners attempt to identify adaptations that would be effective. The typology presented in this paper provides an inventory of the many types and levels of adaptation to climate that are possible in the agricultural sector. Furthermore, by relating specific types of adaptation to public and private stakeholders and to the decision processes actually employed in agriculture, it is hoped that this work will contribute to the development of credible and useful adaptation assessments and programs.

This paper focuses on adaptation options in Canadian agriculture to deal directly with the risks related to climate change. There is an immense variety of potential and actual adaptation options available, including many different types which have been characterized into four main categories. Technological developments involve the development of crops, weather and climate information systems and resource management innovations, including irrigation, by government and industry, to be subsequently adopted by producers sometime in the future. Government programs and insurance involve government agricultural subsidy and support programs (including crop insurance, established income stabilization and *ad hoc* compensation), government resource management programs, and development of private insurance by the financial services sector. Farm production practices involve decision-making by producers and include diversification and intensification of crop and livestock production (including crop substitution), changing land use and topography, irrigation, and timing of operations. The final category, farm financial management, also involves decision-making by producers and includes the use of crop insurance, investment in crop shares and futures, participation in income stabilization programs, and diversification of household income. While this typology provides the structure for differentiating options available in Canadian agriculture, the types remain rather generic. Obviously, for specific farm systems, regions and producers, particular forms of adaptation measures would need to be tailored to local conditions and decision-making processes.

Adaptation in agriculture involves various stakeholders who have different, but often inter-related roles. Governments (and other public agencies), private industries and corporations, and individual producers (farmers) all have a place in the adaptation process. Governments and industries need to be aware how public initiatives (such as increased investment in income stabilization or crop insurance) and private initiatives (such as the development of new crops or crop insurance) relate to producer decisions. Agricultural adaptation options at all levels are part of a larger process, within which decisions are made continuously, in an on-going, 'incremental' fashion, in light of multiple (climatic and non-climatic) stimuli and conditions. Those seeking to promote adaptation need to recognize that producers, in particular, consider climate change, if at all, as part of their on-going management decision-making.

For climate change impact assessment and/or vulnerability assessment in agriculture to be practical, there is a need to incorporate well-founded estimates of the likely employment of adaptation options. This requires an understanding of the processes of decision-making in agriculture; of the ways in which potential climate change adaptation fits into real management decision-making of governments, industries and producers; and of the constraints and stimuli for adaptation. At the same time, any effort to promote and encourage the implementation of adaptation options in agriculture should include an evaluation of options available. This necessitates the recognition of the stakeholder(s) involved in a particular adaptation option, and of how an adaptation relates to broader adaptation decision-making processes (Dolan et al. 2001).

It is also becoming clear that the development of specific adaptation 'product choices' or 'policy prescriptions' (i.e. 'direct' adaptation measures) may not be the most useful means of promoting adaptation in agriculture to climate change in agriculture, or in any sector. The IPCC (Smit et al. 2001) has recognized the practical limitations to identifying and evaluating particular adaptation measures, given their huge variety, their peculiarities in particular applications, and the importance of fitting climate adaptation into on-going processes. A useful alternative to dealing with particular ‘adaptations’ is to work to enhance ‘adaptive capacity’, that is, the broader ability of a system (in this case, agricultural producers, regions or sectors) to cope with climate-related risks and opportunities (Smit et al. 2001). Not only does this allow for local and individual assessment of options, and the incorporation of adaptation into existing risk management processes, but it also recognizes the distinct roles of the public and private sectors. Consistent with the promotion of adaptive capacity is the dissemination of information on climate change risks and vulnerabilities, and on the broad types of adaptations that stakeholders might consider.

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