The Economic Impact of Climate Change on Cash Crop Farms in Québec and Ontario

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ABSTRACT

This study estimated the economic impact of climate change on representative cash crop farms at selected sites in Québec and Ontario over the period 2010 to 2039 using a Mixed Integer Dynamic Linear Programming Model. Five climate scenarios (Hot & Dry, Hot & Humid, Median, Cold & Dry and Cold & Humid) and four weather conditions (the combination of with and without Carbon Dioxide (CO_2) enhancement and water limitation) were selected and combined to form 20 different scenarios. Four major cash crops, i.e. corn, soybean, wheat, and barley, were considered using both reference and improved cultivars. Historical data on crop yields were used to validate the Decision Support System for Agro-Technology Transfer (DSSAT) model which was used to project future yields. Economic variables, such as cost of production and crop prices were projected using Monte Carlo simulation with Crystal Ball Predictor. The results indicate that the optimal resource allocation, outputs, net returns, economic vulnerability, and adaptation strategies were dependent on the climate scenarios, weather conditions, types of crop and variety, as well as site. Water accessibility plays an essential role in farm profitability, especially coupled with atmospheric CO_2 enhancement. Producers at all sites and scenarios were worse off under unfavorable weather condition when water was limited and CO_2 enhancement was absent, especially in Ste-Martine where producers were predicted to have a number of years with successive financial losses. Different climate scenarios also had different impacts on farm management. The representative farm in Ste-Martine performs best under the Hot & Dry scenario if water was adequate, while in North Dundas, the Median or Cold scenarios were preferred. Technological development decreased farm financial vulnerability for all sites and scenarios. Institutional development, in terms of insurance programs and risk management tools, were also used to improve resilience.

RÉSUMÉ

Cette recherche mesure les impacts économiques des changements climatiques sur les principales grandes cultures produites au Québec. Pour ce faire, la recherche utilise un modèle d'optimisation linéaire dynamique unitaire mixte sur la période 2010-2039. Cinq scénarios climatiques (chaud et sec, chaud et humide, médian, froid et sec et froid et humides) ont été combinés à quatre conditions atmosphériques (avec et sans augmentation du CO_2 et avec et sans diminution de la disponibilité de l'eau) ont été sélectionnés pour créer un total de 20 scénarios possibles. Quatre grandes cultures majeures (Maïs, soya, blé et orge) ont été considérées en utilisant un rendement de référence et un scénario d'amélioration des cultivars. Les données historiques sur le rendement des cultures ont été utilisées pour valider le Système de Support de Décision pour le Transfert Agro-Technologique (SSDTAT) qui estime le rendement futur. Les variables économiques comme le coût de production et le prix des grains ont été basés sur une simulation Monte Carlo avec un prédicteur boule de cristal.

Les résultats indiquent que l'allocation optimale des ressources, des produits, des bénéfices nets, de la vulnérabilité et de la stratégie d'adaptation étaient dépendants du scenario de climat, des conditions atmosphériques, du type de cultures, de l'amélioration des variétés ainsi que du site. L'accessibilité de l'eau joue un rôle essentiel sur la profitabilité, tout spécialement lorsqu'elle est combinée à une augmentation du CO_2 atmosphérique. Les producteurs de tous les sites et de tous les scénarios étaient désavantagés face à des conditions climatiques défavorables où l'eau était limitée et l'augmentation du CO_2 absent. Cette situation s'est avérée très bien représentée au site de Ste-Martine où les estimations concluaient que les producteurs subissaient des pertes financières successives sous ce scénario. Les différents scenarios climatiques peuvent également avoir des impacts différents sur la gestion des entreprisses agricoles. Ainsi, les fermes

sondées du site de Ste-Martine ont mieux performé sous le scénario chaud et sec et lorsque l'eau était adéquate. Par contre, le site de Dundas Nord s'est avéré plus productif sous le climat froid ou médian. De plus, l'amélioration technologique, c'est-à-dire l'amélioration des cultivars, peut diminuer la vulnérabilité des entreprises et en augmenter la résilience pour tous les sites, scénarios, conditions climatiques et cultures. Le développement institutionnel comme des programmes d'assurance récolte ou des outils de gestion du risque peuvent également être utilisés pour diminuer la vulnérabilité financière et ainsi augmenter la résilience des fermes sondées.

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CHAPTER 1
BACKGROUND AND INTRODUCTION

1.1 INTRODUCTION

The impact of climate change and the resulting variation in climate can have a serious impact on the agricultural industry. Defined as a change in the state of the climate, climate change can be continually identified by shifts in the mean or variability of temperature and precipitation (Chen 2011). It has been argued that the main cause of climate change is an increase in the emissions of greenhouse gases (GHGs) into the atmosphere, among which, carbon dioxide (CO_2) accounts for more than 60% of the enhanced greenhouse effect. Even though this change is driven by both natural and anthropogenic factors, human activities have been identified by the United Nations Framework Convention on Climate Change (UNFCCC) as the main factor that is altering the carbon cycle, both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks to sequester carbon. This change is predicted to affect every economic sector (Parry et al. 2007) and alter people's behaviour in various ways. Given that climate change and weather conditions will result in more externalities and uncertainties (Tol 2009), especially in agricultural production, it is essential to be aware of what has happened in the past and potentially what will happen in the future.

Records would indicate that the global surface has been warmed by GHGs since pre-industrial times (Alexandrov et al. 2002). This process is widely agreed by scientists as a poleward shift of the thermal limits of agriculture which will favour the northern regions, assuming suitable soil and water is available to grow crops there. Canada, for example, had an average annual increase of temperature by 1.4°C over the period 1948 to 2007 and by 0.2°C from 2007 to 2010

(Parry et al. 2007), compared to an average of 0.74°C worldwide (Environment Canada 2012). Faced with more heat units and a longer growing season, producers will have to modify their variety choices and management strategies, e.g. planting date, according to specific changes happening on their land.

Unbalanced precipitation, accompanied by higher temperatures, accelerates the hydrological cycle and thus results in inefficient use of water resources (Fleischer et al. 2008). Christensen et al (2007) demonstrated that almost all of the North American continent would experience an increase in precipitation except the south-western U.S. As for Canada, even though it experienced a drier than normal year in 2011 (Environment Canada 2012), future projections suggest that precipitation will increase in the range of +20% for the annual mean and +30% during the winter months (Christensen 2007). These changes will require adapting different management strategies and practices because of different soil moisture availability and to prevent exacerbated environmental problems like soil erosion or salinization, chemical runoff and water contamination (Herrington et al. 2010).

Climate change has also been predicted to increase the frequency and intensity of extreme weather events, resulting from the interaction among atmosphere, ocean and land, which may make our climate unstable and increase the risk to agriculture production. Risks in agriculture arise from the inherent uncertainties associated with climate change, and the fluctuation in the Canadian dollar which makes input costs and market prices difficult to predict. But risk is inevitable when pursuing opportunities for development. There exists tremendous potential for the agriculture industry to benefit if the decision-makers can shift from unplanned and ad hoc reactions to proactive, systematic and integrated risk management strategies when confronting various scenarios. Hence, risk management tools, such as improved information and technology, crop insurance programs, and crop diversification, can be adopted to not only cushion damages, but also increase opportunities. But difficulties rise when producers try to obtain sufficient and reliable information regarding weather and market conditions, to predict how crops will respond to these conditions, as well as to evaluate the potential loss and benefits of adopting new management strategies. The cost of risk management is immediate and observable, the benefits which are less visible tend to be underestimated. If producers fail to understand and adapt to the stochastic state due to a lack of resources or planning, they will suffer not only the negative effects on their production and marketing, but also the opportunity costs from potential benefits.

Agriculture has changed over the past decades, but Québec and Ontario still rely on this sector. Rural communities in these regions are subject to vulnerability facing climate change due to decreased economic activity. On the other hand, farming has become more technically sophisticated. Technology development, such as more advanced varieties, machinery and land management practices are available to increase yield. However, most of the existing studies have focused on the average conditions or scenarios using a static or partial equilibrium approach (van Zon and Yetkiner 2003 , Schlenker and Roberts 2009 , Kokoski and Smith 1987), which may exclude indirect and general equilibrium effects, including market prices and interdependence (Arndt et al. 2012). As a result, previous studies often provide only global or regional assessments and ignore the potential benefits from adaptation policies implemented by a higher institutional level (Lobell et al. 2008). Thus, a systematic and dynamic assessment of the uncertainty associated with climate change on representative cash crop producers is essential in order to evaluate the effects of technology development and market fluctuations, as well as improvements in producers' risk management tools, which are important inputs into the policy-making process.

1.2 PROBLEM STATEMENT AND OBJECTIVES

Risk management requires collective action and responsibility at different levels of society, from individual to the national and international community, especially in the case of climate change, which is beyond the control of any individual or country. A large amount of information on the climate and biological impacts has to be estimated before optimal adaptation strategies and policy decisions can be made. The uncertainty associated with climate change can be a problem for agriculture, in particular cash crop producers, because it can increase the economic vulnerability of producers. This study will investigate the economic impact of climate change on representative cash crop producers in regions of Québec and Ontario.

The following four objectives were identified for this research.

(1) To estimate the economic vulnerability of cash crop producers to different climate scenarios over a 30-year period. In addition, the climate scenarios will be modified with conditions of CO_2 enhancement and water availability to see how they impact economic vulnerability.

(2) To investigate how resource utilization and crop selection will change with alternative climate scenarios and conditions.

(3) Technological change can play an important role in addressing the uncertainty associated with climate change. Technological change, in the form of improved crop varieties, will be investigated as a means of addressing the problem of climate change.

(4) Institutional mechanisms, such as insurance, can be used to reduce the risk associated with climate change. This study will investigate the role of insurance in examining problems associated with climate change and as a means of decreasing financial vulnerability.

1.3 ORGANIZATION OF THE STUDY

This study selected three specific sites, Ste-Martine and St-Sébastien in Montérégie west and North Dundas in Ontario, to address the above issues by evaluating both physical and economic impacts of projected climate change scenarios and weather conditions on the net returns of representative cash crop farms. A Mixed Integer Dynamic Linear Programming (MIDLP) model was developed to optimize farm net returns and corresponding resource allocation, as well as to see the number of years when negative farm income occurs under each climate scenario. The impact of technology will be analyzed by comparing the results of models using only existing crop varieties and those using both existing and improved varieties. The present study also investigates how institutional change affects returns through modeling both existing and modified crop insurance programs into the mathematical model.

The next chapter reviews the relevant points concerning climate change, methods used in this study and different approaches for adaptation. This is followed by a description of the studied sites in Chapter 3. Chapter 4 consists of describing the model data and the theory behind the analytical method. Chapter 5 presents the analysis, results and discussions, followed by the conclusion in Chapter 6.

CHAPTER 2
LITERATURE REVIEW

The causes and consequences of global warming are very diverse (Tol 2009). Among the economic sectors that are affected by climate change, agriculture production is one of the most sensitive (Alexandrov et al. 2002), especially in environmentally and economically vulnerable regions (Antle 1995). For example, relative to a no climate change baseline, food security in Tanzania is projected to be threatened because of the serious deterioration of the agricultural potential as a result of climate change (Arndt et al. 2012). Even though there does not exist a food security crisis in North America, the yield of corn and soybeans in the Corn and Wheat Belt of the U.S. have been negatively impacted by warming, resulting in a yield decrease of 17% for each 1°C warm-temperature anomaly over the period 1982 to 1998 (Lobell and Asner 2003). Due to the dependence of agriculture on natural conditions, there exist significant variations across regions and between years. North American is endowed with a dynamic agriculture sectors, and Canada could potentially benefit from climate change owing to the trend in the shift in cropping zones.

Risks faced by farmers can be divided into two main categories, namely the risks during production process and those in the market (Antón et al. 2011). Taking production into consideration first, it can be demonstrated that crop yield changes due to climate change are likely to vary according to different climate scenarios, crop varieties (Hareau et al. 1999) and agricultural region (Brassard and Singh 2008). For example, it will widen the production gap between developing countries and developed countries with increased malnutrition (Rosenzweig and Hillel 2007). But in general, the main causative factors controlling crop yield tends to be the same.

They are the direct CO_2 fertilization effect (Alexandrov et al. 2002), and the indirect CO_2 effects, for example, the increase in temperature which accelerates crop maturation, the changes in soil moisture and nitrogen supply (Brassard and Singh 2008).

2.1. DIRECT EFFECT FROM CO2 ENHANCEMENT

The history of scientific discovery of climate change began in the early 19th century, when the greenhouse effect was first identified. But not until the 1960s did the warming effect of carbon dioxide became increasingly convincing. Its effect on photosynthetic responses of plants was first recognized in 1988, which is widely known as the direct CO_2 fertilization effect (Warrick 1988). In Québec, research conducted in the southern part of the province indicated that the optimal thermal conditions and crop maturation are influenced by growing season temperature, which turns out to be a result of increasing CO_2 concentration level (Brassard and Singh 2008). However, things may be different when dealing with different crops. C_3 plants, such as soybean, wheat and barley, which account for more than 95% of earth's plant population, can flourish in cool, wet climate conditions with lower levels of light, due to their efficient and stable process of carbon fixation (Cowling and Sykes 1999). C_4 plants, such as grain corn, tend to grow in hot and dry environments because of their high water-use efficiency. El Maayar et al. (1997) showed that C_4 crops, such as corn and sorghum, would benefit by climate change, at least in terms of the CO_2 fertilisation effect, while C_3 crops were projected to have decreased yields in most agricultural regions.

2.2. INDIRECT EFFECTS

Attention must also be paid to the indirect effect from CO_2 concentration enhancement. With increasing temperature, some winter crops, such as wheat and barley, which flourish in most regions of Canada, may find a warmer climate detrimental, while summer crops like corn will be positively affected (Hareau et al. 1999). Precipitation can influence the hydrological cycle and soil moisture availability along with evapotranspiration (Brassard and Singh 2008), and thus crop yields. Also, higher water temperature and extreme events, such as floods and droughts, are likely to happen with increasing frequency and magnitude. They can exacerbate different types of water problems and cause negative impacts on ecosystems, as well as human health (Quevauviller 2011). "Precipitation deficiencies or increased variability would be detrimental" (Hareau et al. 1999, p.8), especially to agricultural production. The U.S. drought in 2012 might be regarded as a good example of a severe climate anomaly. While most of the United States suffered from a decrease in crop yield due to the unexpected drought, Canada benefited from the increased crop prices caused by non-decreasing demand. Nonetheless, similar to direct CO_2 fertilization, precipitation also results in different effects depending on the crop involved. For example, an increase in precipitation could be detrimental to winter crops, but it can have a positive effect on rainfed summer crops, such as corn (Hareau et al. 1999). The overall tendency of nitrogen uptake by crops is predicted to increase in the future scenarios, especially in terms of northern agricultural regions and crops such as corn and soybean (Brassard and Singh 2008). This leads to more fertilizer being applied by farmers for the purpose of higher crop yield, which would be a benefit from future climate change.

According to Brassard and Singh (2008), the factors that affect crop yield related to climate change are usually interdependent and it is difficult to isolate and recognize their individual components. This phenomenon will lead to a dilution of the effects of climate change to some extent, or even cancel the impact of some individual factors. For example, the atmospheric CO_2 concentration can influence the ratio of carbon assimilation per unit transpiration, namely water-use efficiency, through stomatal conductance and thus may change the response of crops to future droughts (Cowling and Sykes 1999). Research conducted in Québec shows that in order to at least maintain the current level of agricultural production, irrigation must be increased due to declining soil water availability, and plant nitrogen uptake must be increased even though the CO_2 fertilization effect was accounted for (Brassard and Singh 2008).

2.3. ECONOMIC IMPACTS OF CLIMATE CHANGE

Apart from the above mentioned technical effects resulting from climate change, climate change variables (temperature, change in precipitation and CO_2, frequency of extreme events and sea level rise) will also cause changes in food system assets, production activities, storage, processing, distributing, and consumption patterns (Wilcock et al. 2008), as well as policy making processes at the institutional or political level. For example, climate-driven environmental changes, together with local economic conditions, will result in significant changes in future land-use (Reilly 1999) and risk management tools used by farmers. Supply and demand of other production inputs, such as labour, water, equipment, energy, etc., will also be affected (Seyoum-Edjigu 2008), and leads to an adjustment or reallocation according to comparative advantage (Rosenzweig and Hillel 2007). Furthermore, increased uncertainty will strengthen the development of international markets (Fleischer et al. 2008), while some economic costs should be expected if adaptation to climate change occurs. On the other hand, it is not the average conditions or merely temperature and precipitation that affect crop yield. "Uncertainty pervades the behaviour of ecological systems, ensuring that we cannot know in advance whether some system is or is not resilient" (Perman 2003, p.94), thus it is the "inter-annual and intra-annual variation" and extreme events, along with the complexity of agriculture, which determines the critical climatic threshold and should be accounted for in risk averse models (Bryant et al. 2000).

2.4. METHODOLOGY REVIEW

2.4.1. Agronomic Simulation

A large number of climate models have emerged during the past decade, and they are usually evaluated through their ability to replicate past climate changes (Benestad 2003). Simulation models are usually the first step in this type of analysis by incorporating not only plant-growth theories, but the distribution of weather outcomes over the growing season (Schlenker and Roberts 2009). The Global Circulation Model (GCM) has been widely applied to create different climate change scenarios in a variety of regions (Alexandrov et al. 2002 , Schut et al. 2001 , Blanc and Strobl 2013). When accounting for the agrometeorological conditions in selected regions, the yield simulation results of CERES and CROPGRO models have been shown to be consistent with measured data for winter wheat and soybean (Alexandrov et al. 2002). But the current CROPGRO model cannot simulate soil nitrogen balance or organic carbon. The most current crop yield and changes are simulated with the Decision Support System for Agrotechnology Transfer (DSSAT) crop model (Brassard and Singh 2008). It does, however, place a number of simplifications and limitations during the process of building the model. Risks, such as weed, pest, disease, as well as extreme weather events, are either assumed to be controlled or totally ignored, especially in terms of technical changes (Alexandrov et al. 2002). Thus, in order to address these issues, a modularly re-designed and programmed DSSAT cropping system model (DSSAT-CSM) was developed to take into account a number of additional factors, such as extreme weather events, technological change, etc. (Jones et al. 2003).

2.4.2. Economic Analysis

Apart from the modeling of physical and biological processes of agriculture, social-economic parameters representing human behaviour and cognition should be identified (Andersen and Mostue 2012 , Just 2001). On the basis of the crop yield simulated by the agronomic models for different scenarios, mathematical models are built to inform decision-making units of the way to allocate resources according to different climate and economic conditions, and thus optimize their net income.

2.4.2.1. Macroeconomic and GE Models

From an economic perspective, there are several approaches to analyze the economic impacts of climate changes. Macroeconomic models, which represent the whole economy, can be adjusted to integrate the interaction between climate and economy (Carraro et al. 2003), and to capture the structure of social-economic changes (Just 2001). In many of these studies, attention is paid to the overall consumer welfare and social costs without determining whether the related resource requirements are met or not. There tends to be a bias and large variability in the results based on the assumptions made prior to the analysis, especially in the case of dynamic problems (Romer 1990). Furthermore, their analysis is based on traditional formal theory and economic analysis, and thus more extensively recent theoretical advances in the theory need to be incorporated into their analysis (Carraro et al. 2003), which may not be available for some newly developed topics. Similarly, general equilibrium (GE) models can only operate at a highly aggregated level to investigate the interactions between agriculture and other sectors in the economy (Palatnik and Roson 2012), which allows resources to be re-distributed in response to economic incentives (Schlenker et al. 2006). The consumer-producer-surplus approach, for example, is often used to assess the impact of future climate change on future projections, which focuses its attention on changing demand and supply due to certain commodity's prices and income effects, rather than maximizing the net return (Yates and Strzepek 1998).

2.4.2.2. Ricardian Approach

From a relatively less aggregated perspective, a Ricardian model, for example, the model developed by Mendelsohn, Nordhaus and Shaw (1994), can also be used to test the economic effects of climate change. Another example of a modelling approach is the hedonic model of farmland pricing. This approach uses land values based on actual transaction and the attributes of the land being used to calculate the direct impact on each farmer (Schlenker et al. 2006). But since large amounts of data must be gathered and manipulated, even with net annual income regressed on climate and other control variables, the objective value is still not guaranteed (Fleischer et al. 2008).

2.4.2.3. PARTIAL EQUILIBRIUM MODELS

By contrast, partial equilibrium models include only a limited number of sectors in the economy (Palatnik and Roson 2012). The advantage of partial equilibrium models are that they can provide greater detail of sectors and individual behavior that can assist the policy process (Kokoski and Smith 1987). In this regard, partial equilibrium models can be built with specific characteristics of agricultural markets. A potential problem with these models is the omission of variables, especially variables carrying high empirical weight, which may lead the models to be untrustworthy (Schlenker and Roberts 2009), or not robust if this decentralized approach excludes the inputs with bias (Romer 1990).

2.4.2.4. Econometric Approach

Econometric models have been used to evaluate the impact of climate change because of their capability to categorize and integrate a complex set of variables (Cheng et al. 2012) and capture nearly all the responses of climate change (Markoff and Cullen 2008). "It can control in various ways for precipitation, technological change, soils, and location-specific unobserved factors, and all show a similar nonlinear relationship between temperature and yield" (Schlenker and Roberts 2009, p.1). These models can be used to evaluate the direct impact of considered factors on farmers' net return using either cross-section or time series data, and conduct a sensitivity analysis afterwards (Schlenker et al. 2006). On the other hand, these models can also be used to estimate confidential intervals and to compare the observed trends of climate change and economy with those simulated by climate models (Benestad 2003). The regression framework, however, cannot take cropland area change into consideration (Blanc and Strobl 2013), and is limited when estimating dynamic processes (Schlenker and Roberts 2009), since it typically uses average data for the analysis (Choi and Fisher 2003).

2.4.2.5. Optimization Methods

Optimization models that maximize farmer's profits are often used and can integrate crop growth model information into an economic decision model (Lehmann et al. 2013). This technique can be used in a parametric analysis to examine the impact of climate change (Roshani et al. 2012), which not only concerns optimizing profits, but also reflects the production risks and management decisions on a field scale (Lehmann et al. 2013). A sensitivity analysis can be carried out that can incorporate a large number of farm specific variables and constraints.

John et al. (2005) used a whole-farm linear programming model to explore the consequences of several climate scenarios based on discrete stochastic programming (DSP). DSP has the advantage of being a sequential decision framework that can incorporate risks which makes it well-suited to a variety of firm-level problems. But its usage is strictly limited by the cost of model construction and the availability of data (Apland and Hauer 1993). A Mixed Integer Dynamic Linear Programming (MIDLP) model was used by Seyoum-Edjigu (2008) to investigate the economic impact of climate scenarios on producers' gross margin. This model included a long planning horizon and a large number of stochastic variables. Crop selection and acreage decisions were based on optimizing the farmers' net income.

2.5. ADAPTATION STRATEGIES

Much of the research to date regarding climate change and agriculture has been on mitigation; however, since it is unavoidable, more attention is being paid to adaptation recently (Vermeulen et al. 2012). Mitigation and adaptation can be mutually reinforcing (Johnston et al. 2012), especially in a situation of increasing climate variability (Rosenzweig and Hillel 2007). Adaptive strategies are needed in order to protect local food supplies, assets and livelihoods, avoid damage to farmers' income, and protect the ecosystems (Wilcock et al. 2008). The way towards adaptation is diverse (Adger et al. 2005). A global solution is a necessity, however, a polycentric system where enterprises at multiple, smaller scales may complement each other can start the process of mitigation (Ostrom 2010). Generally speaking, a systematic approach to agricultural risk management towards climate change should be structured around three layers of risk that require differentiated responses: normal (frequent) risks coped with at the farm level, market intermediate risks retained by market tools, and catastrophic risks requiring government assistance (Antón et al. 2011). Whichever strategies are selected, they should be integrated together so as to guarantee the sustainability and resilience of agriculture in the context of an uncertain future challenged by climate change.

2.5.1. Agronomic Approach

At the farm level, the existing technology that will likely be used when coping with a warmer climate includes irrigation, cover, and early market products (Fleischer et al. 2008).

Shorter-maturing varieties and wide-spread use of grain drying technology are two major developments in corn production, both of which can be employed to reduce the risk of losses due to early frost (Reilly et al. 2003). Other strategies such as changes in the timing of operations, as well as land and irrigation management could also be feasible (Easterling 1996) given the past experience of agricultural research applied to production (Hareau et al. 1999). Diversification and rotation are other strategies that are likely to occur when coping with climate variation from year to year. These strategies would reduce the risks of pests and diseases in crop production, and make crops less vulnerable (Alexandrov et al. 2002). These strategies can offset either partially or completely the loss of productivity caused by climate change (Easterling 1996).

2.5.2. Economic and Institutional Approach

Farmers' net returns depend not only on the biophysical conditions and thus crop yield changes that result from climate change, but also on the cost of production and market prices (Lobell et al. 2008). The economies of scale has led to an overall expansion tendency in agricultural production (Easterling 1996), which can benefit from lower costs of production, potentially more access to information and policy-making processes, as well as regional market power when faced with climate change. A mild increase in temperature is beneficial only when the markets for farm products are well-developed (Fleischer et al. 2008), either regional or international. Thus, economic adaptation strategies such as investment should not only be in new technologies and infrastructure construction, but can also be used to develop the input and output markets (Easterling 1996). A sound market that can contribute to reducing farmers' risk should be stable, transparent and have long-term credible monetary policies (World Bank 2013). Flexible exchange rates can be effective in absorbing shocks using international market power (Dornbusch 1976).

The development of new institutions should be carried out to reinforce economic adaptation. International trade relationships and arrangements need to be strengthened so as to compensate for different climate change effects in different locations (Vermeulen et al. 2012). The risk management technologies and approaches have been well-developed in some countries around the world such as Australia, Canada, and the United States, but they should be tailored to the country context when adopted by other countries, especially for developing ones (Vermeulen et al. 2012). Adaptation at this level does not aim at achieving a welfare optima, but maintaining and enhancing welfare under a changing environment by continuously influencing the decision-making processes at the economic level (Ciriacy-Wantrup and Bishop 1975), which enhances the social environment for the other systems to function and provides direct support to vulnerable people (World Bank 2013). While farmers tend to be optimistic about their ability to identify and implement adaptation options at the farm level, some institutional barriers turn out to be major impediments (Johnston and Hesseln 2012), since government tends to enact legislations favouring the "public" interest but threatening producers' benefit without compensation (Dornbusch 1976). Changes in institutional structures and relationships can also be used to reduce climate change risks and thus agricultural vulnerability (Antón et al. 2011).

Existing institutional adaptation frameworks include several interrelated steps, which assess the fundamental goals and resilience of individuals in the face of adverse events, understanding the internal and external risks and opportunities associated with the environment, considering the potential risk management tools at different levels of society and assessing the resources and obstacles they have (World Bank 2013). The insurance system has been the primary risk governance tool for industrialized society thus far (Phelan et al. 2011). Both the UN Climate Convention and the Kyoto Protocol have included the provision of insurance as a mechanism of risk reduction, which deals with the risk of natural disaster and manages the events following disasters (Antón et al. 2011). Owing to the risky nature of agriculture and the unpredictable uncertainties brought about by climate change, it is appropriate to encourage or even subsidize farmers to insure their crops and bring their interests and concerns to the attention of policymakers (Schmitz et al. 2010).

"Successful climate change adaptation requires careful consideration of technical and social dimensions" (Costello et al. 2010, p.8). Adaptation research is an action-oriented undertaking where mutual learning among participants at the farm, economic and institutional levels (Jones and Preston 2011). In addition, an understanding of cross-level interactions (Phelan et al. 2011) is important, while trade-offs and synergies can take place among collective actions. As their financial losses are limited by government policies, farmers may show increased willingness to accept yield losses, and thus shift from risk-averse to risk-seeking behaviour (Reilly et al. 2003). Some individual farmers, for example may have perceived the risks and opportunities in biophysical factors associated with climate change and made technical improvements in their operations. Climate change, however, should be regarded as a long-term phenomenon and the coping strategies required to address this issue should be at not only the farm level, but also the institutional level (Bryant et al. 2000). Changes at the institutional and political levels can result in government failure, which is defined as its limited ability to maintain long-term policies. If this occurs, government failure will increase the uncertainties associated with agricultural productions and farmers' costs (Schmitz et al. 2010). Hence, the potential significant co-benefits to adaptation and mitigation strategies (Kenny 2011) is a result of collaborative adaptive co-management (May and Plummer 2011), which makes it necessary to maintain a more diverse and sustainable adaptation structure (Pukkala and Kellomäki 2012).

CHAPTER 3
SCOPE OF THE STUDY

Technological developments in agriculture have increased production; however, weather conditions and soil quality still remain important factors in determining the profitability of agriculture. Québec and Ontario are two provinces which make substantial contribution to Canadian agriculture production owing to their relatively mild temperature and fertile soil. The Census of Agriculture (Statistics Canada 2011) estimated that there were 29,437 and 51,950 farms in Québec and Ontario respectively, ranking 4th and 1st in Canada and these farms accounted for 14.3% and 25.3% of Canada's 205,730 farms. The number of census farms in Canada has been declining since 1941 as a result of urbanization in the1950s. Compared to the 2006 Census of Agriculture, both Québec and Ontario have encountered a 4.0% and 9.2% decrease in their total number of farms, which is slightly lower than the 10.3% decrease at the national level (Statistics Canada 2006 , Statistics Canada 2011). In order to estimate the potential impact of climate change on these two provinces, two regions, Montérégie-west and Dundas County, were selected to be evaluated and compared. The former is located in southern Québec while the latter is located in eastern Ontario. They are characterized by slightly different agronomic conditions, production structure and institutional environment.

In Québec, agriculture activities are concentrated in the southern part of the province, especially in the Montérégie region owing to its favourable climate conditions and fertile soil. Covering a land area of 371,370 ha in 2008, of which 84.98% is in the agricultural zone[1]. This region contains nearly a third of the farms in Québec and plays a critical role in crop and livestock

[1] These data do not include that of the Haut-Richelieu part of CRE Montérégie-East

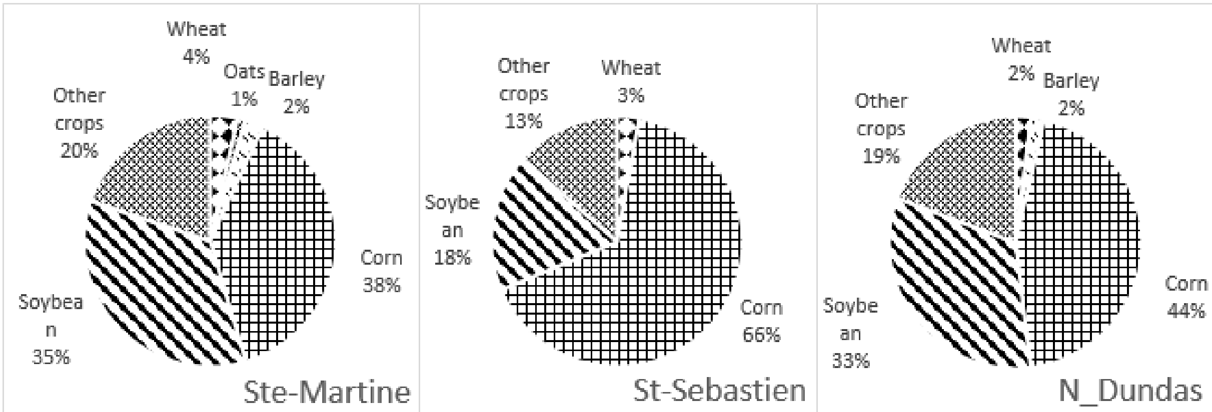
production, as well as the food processing industry (Institut de la Statistique du Québec 2012). Of the total farm area in Ontario in 2011, 70.5% is in cropland and a majority (74.1%) of this is in field crops (Statistics Canada 2011). The percentage of cropland in the united counties of Stormnot, Dundas and Glengarry (SDG) is even higher (74.9%), with 72.7% in field crops (Institut de la Statistique du Québec 2012).

From an agronomic perspective, these areas are located in the North Temperate Zone, which has rich and varied soil, a warmer temperature, a relatively long growing season from mid-April to mid-October, and a stable freshwater supply. All of these factors contribute to the development of agriculture in Montérégie-west and SDG. Montérégie-west has a reported total agricultural area of 308,585 hectares in 2006, which is approximately 9% of the Québec total. The total number of farms in the region was estimated to be 2,740 in 2011, accounting for 9.3% of the farmers in the province (Institut de la Statistique du Québec 2012). Eastern Ontario does not contribute the most value to the provincial agriculture sector when compared to the southern and western areas. The total farm area in SDG decreased by 3% since the last census (2006) and was 193,281 ha in 2011, which is 3.77% of the total agricultural land area in Ontario. The number of farms declined even faster by 12% during this period. A total of 1,577 farms have been reported in the united counties in 2011, which accounts for only about 3% of the Ontario total (OMAFRA 2011). Decreases in the number of farms and the agricultural land in the two regions are consistent with the situation in both provinces and Canada as a whole, while this general trend has resulted in the appearance of larger-sized farms due to either economic or demographic factors. The representative farm size was estimated to be approximately 10 percent higher than that of the province in 2011, and both of them show an increasing trend during the past decades. Corn is the largest crop grown in Montérégie-west with an area of 108,248 ha, which is 36% of total agriculture land in 2011. The area devoted to soybean production has experienced an increase of 341.6% during the past two decades due to the increase in the market price, which lead it to be the second largest crop in this region with 42,472 ha and 14% of the total agriculture land. The same situation has occurred in the SDG counties. Grain corn ranks first with 51,754 ha, accounting for 6.29% of the provincial corn production. It occupies 26.8% of the total agricultural land in this region which is an increase from 18.9% in 2006 due to increased crop prices and declining beef cattle and pig prices. The percentage of agricultural land occupied by the second largest crop, soybeans, has also increased from 16.9% to 22.7% between the censuses, resulting in 43,824 ha in total (Statistics Canada 2011 , Statistics Canada 2006).

In this simulation, two specific sites in Montérégie-west and one in the SDG counties were selected so as to better illustrate the representative farm type, weather conditions and soil type, etc. They are Sainte-Martine which is located in the regional county municipalities (RCM) of Beauharnois-Salaberry, Saint-Sebastien in the RCM of Le Haut-Richelieu, and North Dundas in the SDG counties in Ontario. Their relative location can be found in Appendix 1. According to the Census of Agriculture 2011, North Dundas has a land area of 33,243 ha in crops, while the crop land in Ste-Martine and St-Sébastien are 7,339 ha and 4,867 ha respectively.

Four major cash crops, including grain corn, wheat, barley and soybean, are assumed to be cultivated on the representative farms in the selected sites. Their historical yields were first calibrated and validated using the agronomic model, and then simulated to evaluate the economic impacts of climate change. The shares of the total land in crops are shown in Figure 1.

Figure 1: The shares of the total land in crops in Ste-Martine, St-Sébastien and North Dundas



Note: The data of land area covered by oats and barley in St-Sébastien is not suppressed to meet the confidentiality requirements of the Statistics Act.

Source: Statistics Canada, 2011 Census of Agriculture, Farm and Farm Operator Data

CHAPTER 4
RESEARCH DESIGN AND DATA DESCRIPTION

Two cultivars for each crop were simulated over a 30 year time horizon, the period 2010 to 2039. The reference cultivar is the currently grown cultivar and their performance and yields were validated by comparing the simulated values from the DSSAT model with the observed values. The other is an improved cultivar. It is a simulated result due to plant breeding which makes them resistant to disease, insects and other pests as well as resistant to some climatic conditions, such as drought, heat, frost, shattering, etc. As for the cultivation practices, conventional tillage is the predominant tillage practice in these regions. Thus, conventional tillage, with its corresponding cost, was the cultivation practice assumed in this study.

Given the uncertainties associated with the direction and magnitude of future climate change, five climate scenarios were considered. This allows for a better understanding of the potential threats and opportunities under each scenario and encourages related adaptation strategies to be applied. The five scenarios selected were: 1) hot and dry; 2) hot and humid; 3) median; 4) cold and dry; 5) cold and humid[2]. In addition, these five scenarios were modified to include different combinations of CO_2 enhancement and water limitation. Given these combinations there are 20 different climate scenarios and conditions considered for each site. Given the uncertainty associated with climate change, climatologists were unable to provide a probability for any one scenario, so it was assumed that each scenario had an equal probability of

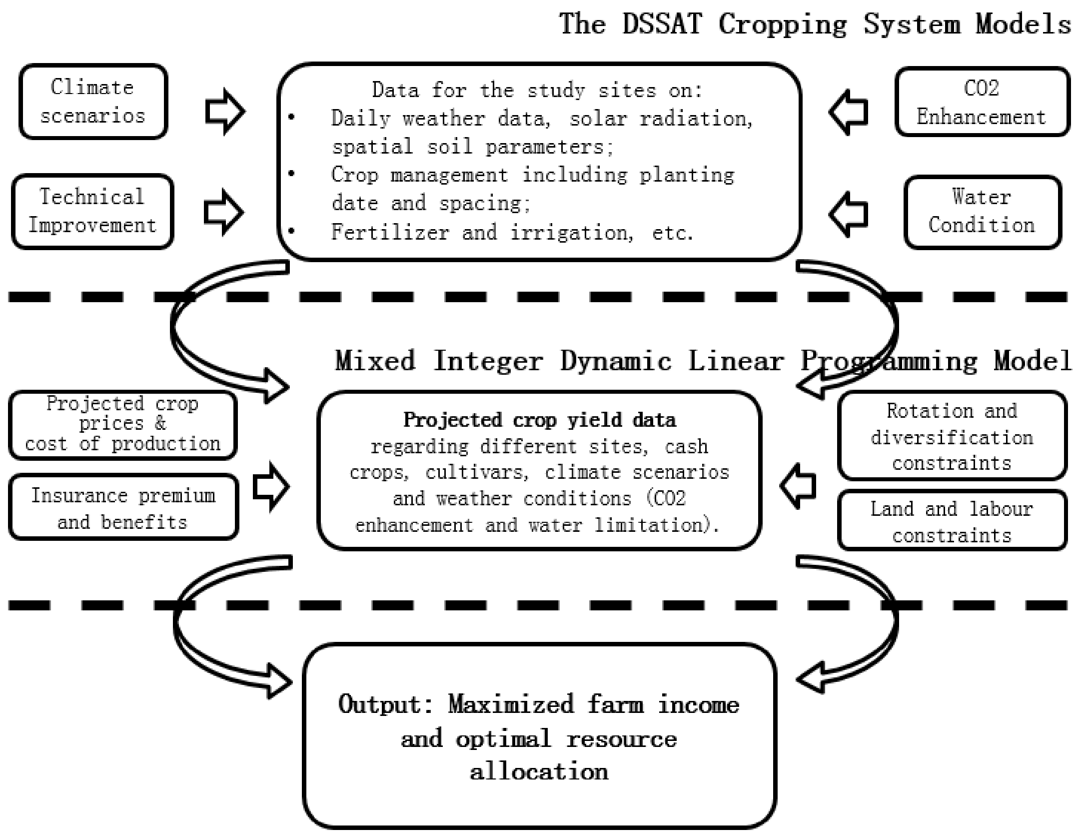
[2] They were chosen to represent differentiate agro-climatic indices by climatologists in OURANOS based on their understanding of representative climate scenarios that could occur over the next 30 years. For example, the hot and dry scenario means a scenario with increase in temperature and decrease in the precipitation pattern.

occurring over the planning horizon. Once a scenario was selected, it was not subject to change over the time period being analyzed. For example, if the producer is facing Hot & Dry with CO_2 enhancement and water limitation in the first year, then this will last over the following projected 29 years.

4.1. THE DSSAT CROPPING SYSTEM MODEL

The Decision Support System for Agro-Technology Transfer (DSSAT) model is the most widely used crop growth model, which was designed to simulate crop yields and development under different scenarios (Jones et al. 2003). In this study, it was used by the Geography Department of the University of Montreal to simulate future crop yields. Data requirements include soil qualities, weather conditions (e.g. solar radiation, day length, daily minimum and maximum temperature, rainfall and atmospheric CO_2 concentration) and crop management practices (e.g. fertilizer, irrigation, tillage and spacing, etc) (Thorp et al. 2008). The crop simulation model was applied to simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics. The model was validated using historical yield data of the reference cultivar for all four crops, and was then used to simulate plant yields over the future 30 years (2010-2039), for both the reference cultivar and the improved cultivar, based on the climate input data of the various scenarios. The future yield data were generated for all four crops, which were corn, barley, wheat and soybean, under all stated conditions: with or without CO_2 enhancement; and with or without water limitation. The output from the DSSAT cropping model is an input into the mathematical programming models which were used to analyze the economic impact of climate change and agricultural vulnerability. A brief structure of the process of analysis for this study is described in Figure 2.

Figure 2: Structure of the analysis process



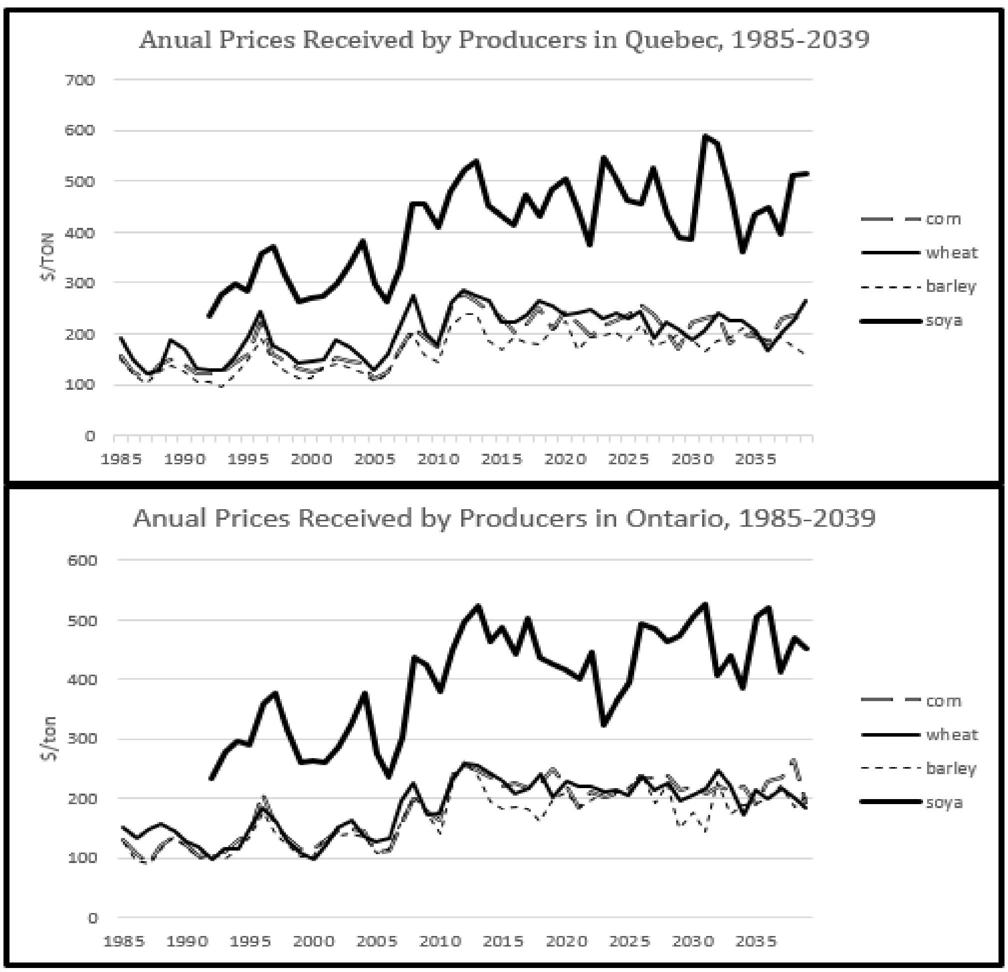
4.2. DATA PREPARED

4.2.1. Projected Prices and Costs

It is assumed that the producers from all sites are price takers in the national or international market, and no widespread extreme events occurred in either the historical or future time periods. The annual crop prices received by Ontario and Québec producers were used to project future prices. Several individuals confirmed that there was no significant difference between the provincial and regional prices (St-Pierre 2013). In order to capture the trend and variability of crop prices and project them into the planning horizon of the model, a series of monthly historical price data were selected for each crop. Historical prices for grain corn, wheat and barley were for the period 1985 to 2010, while the price for soybean started in 1989. Both of them have a cycle of 6 years. Crystal Ball's CB Predictor (v.11.1.2.2) (Werchman and Crosswhite 2006) and Monte Carlo (MC) simulations were used to predict the prices into the future until 2039. CB Predictor uses time-series methods to analyze the underlying structure of the historical data, including Single Moving Average, Seasonal Additive, Double Exp Smoothing, and Holt-Winters' Multiplicative, etc. so as to see which one provides the best goodness-of-fit and uses it to forecast into the future. Using the error measure methods, such as RMSE, MAD and MAPE, it projects the trends and patterns to predict future values providing a confidence interval at 5% and 95% as default indicating the degree of uncertainty around the forecast. The forecasted values are then evaluated and validated with statistics, such as Theil's U and Durbin-Watson (DW). Then, a Monte Carlo method was applied to identify the probability distribution over the historical and projected data. Through generating and aggregating monthly prices randomly over the domain, the annual average crop prices can be obtained. The trends and variability in crop prices in both provinces are summarized in Figure 3. Since this study focuses on the average result over the planning horizon, the price and COP are forecasted separately in Québec and Ontario. So different patterns are allowed in the two provinces.

CB Predictor and Monte Carlo simulations were also used to simulate the cost of production (COP). The budget for each crop was projected into the future. Provincial COP information from La Financière Agricole du Québec since 1999 were used to reflect the budgets at the Ste-Martine and St-Sébastien sites, after adjusted by regional numbers from Centre d'Expertise en Gestion Agricole (Tremblay 2013). In North Dundas, it is the Field Crop Budgets from Ministry of Agriculture, Food and Rural Affairs (OMAFRA 2013) and Ontario Farm Input Price Index (Statistics Canada 2013) since 1971 were used to make projections. In this study, the cost per hectare for each of the four crops includes both fixed cost and variable costs. The insurance expenses and salaries were excluded because they were analyzed separately in other parts of the mathematical programming model. The hourly wage was assumed to start at $15 in 2010 and increases at a minimum rate of 2% per year. Land and machinery rental expenses were not included in the budget because it was assumed that this capital was owned by producers. Machinery depreciation was captured and a zero residual value was assumed at the end of the planning horizon while maintenance costs were still included in the costs.

Figure 3: Historical and Projected Crop Prices in Québec and Ontario, 1985-2039



Source**:** Fédération des producteurs de cultures commerciales du Québec (FPCCQ), Ontario Ministry of Agriculture and Food (OMAF), and Statistics Canada

In order to increase the precision of the cost estimates, the annual cost of production was obtained by separately projecting the cost for each input and then combining the input costs together. In addition, the simulation results from the DSSAT cropping models indicated that the improved cultivar had a significant higher yield than the reference cultivar for each crop under most of the scenarios, conditions and sites (Table 1). Appendix 2 shows the simulated yields for all scenarios, sites, crops and cultivars. Crop yields increased in Ste-Martine after using the improved cultivar, especially when water is not limited. Barley was the crop with the greatest increase in yield among the four, especially in the median scenario and coupled with no CO_2 enhancement or water limitation. Soybean was hardly affected by the technology improvement and even suffered from losses in St-Sébastien. Crops in Québec may expect much higher yield improvements when the improved cultivar was adopted, especially in St-Sébastien. The COP of the improved cultivar was adjusted by site and crop, as higher expenses for pesticides, drying, storage, fuel and electricity, etc. were expected (Appendix 3).

Table 1: Average Yield Increase Due to Cultivar Improvement

	North Dundas	Ste-Martine	St-Sebastien
corn	10.49%	38.56%	62.03%
wheat	39.18%	77.93%	178.61%
barley	42.95%	121.32%	200.65%
soya	16.23%	2.30%	-17.54%

4.2.2. Crop Insurance Programs

There was a reported 50 percent increase in insured crop area in Montérégie west between 2000 and 2010, and grain corn alone represents 62 percent of the total insured area in 2010 (La Financière Agricole du Québec 2010). In the present study, the producers were assumed to be risk neutral and their objective was to maximize their net returns. In order to achieve this goal, four major types of crop insurance offered by La Financière agricole du Québec and Agricorp were included in the model. The Individual Crop Insurance in Québec (La Financière Agricole du Québec 2013) and the Production Insurance in Ontario (Agricorp 2013) protects producers from yield reductions caused by factors beyond their control at various levels. In order to account for producers' commitment to this program, their costs of production were initially adjusted on a per hectare basis using corresponding premium and compensation depending on the difference between simulated yield and covered probable yield, which is the average projected yield of the previous five-year period times the coverage rate.

The Farm Income Stabilization Insurance (ASRA) program (La Financière Agricole du Québec 2013) similar to Risk Management Program (RMP) in Ontario (Agricorp 2013) provides protection against adverse market price fluctuations. The AgriStability program is based on the principle that governments share with the individual the cost of stabilizing annual income with the participating producer (La Financière Agricole du Québec 2013 , Agricorp 2013). As long as the margin[3] drops by more than 30 percent in relation to the reference margin[4] for a given participation year, the decline would be partially offset (70%) by the federal and provincial governments. Producers will receive only one payment from ASRA or RMP and AgriStability whichever is higher. The AgriInvest program can also be taken advantage of without influencing the marginal benefits per hectare of land (La Financière Agricole du Québec 2013 , Agricorp 2013). It allows participants to make an annual deposit into an account of up to 1.0 percent of their operation's adjusted net sales (Parry et al.) of allowable products and to receive a matching

[3] Generally speaking, the production margin corresponds to the difference between the participating producers' farming revenue and costs (La Financiere Agricole du Québec).
[4] The reference margin corresponds to the Olympic average of the margin in previous five years, which excludes the highest and lowest years.

government contribution, as well as the interests. These insurance programs were modeled in order to create a dynamic platform which links the average income and yield of previous years with the future, and can also be used as an indication of the economic vulnerability under different scenarios. Most of the insurance programs, except Individual Crop Insurance and Production Insurance, are not in the optimization procedures, but their risk aversion capability will be evaluated based on the annual optimal farm performance.

4.3. MATHEMATICAL PROGRAMMING MODEL

Producers need to make many decisions involving technical agriculture and their economic activities so as to maximize their profit every year. For example, producers have to make rotation and diversification plans, decide the seeding area for each crop, the amount of hired labour, insurance coverage, etc. In addition, most of their decisions are subject to some constraints. Seeding area is limited by the total cultivable land while hired labour is dependent on how many labour hours are available in a particular period. Insurance participation is also constrained by some qualification requirements set by certain institutions. One method that is often used to solve such complex decision problems and provide for an optimal solution is a mathematical method called Linear Programming (LP). These models take the following form:

Maximize $$Z = p_n^T S_n - c_n^T X_n - w_n l^T X_n,\ n=1, 2, \ldots, 30 \tag{1}$$

Subject to $$X_n I \leq b \tag{2}$$

$$l^T X_n \leq d \tag{3}$$

$$X_n \circ \tag{4}$$

$$X_{ij} \leq \mathrm{a} X_n I \tag{5}$$

And $$X_n,\ S_n \geq 0 \tag{6}$$

Where in the objective function (1), Z is the net return that needs to be maximized. X_n is the cultivation area for each crop with different Individual Crop Insurance coverage at year n, S_n

is the quantities of each crop sold at year n[5]. p_n, c_n and w_n represent the correspondent crop prices, cost of production (including the net payment to the Individual Crop Insurance) and hourly wage to hired labor. l is the labor requirement for each unit of cropland. Equation (2) and (3) are the land and labor constraints where b and d represent the total land and labor available for the representative farm, which are 350 ha and 4,725[6] hours respectively. Y_n, equation 4, is the yield per land unit for each crop and the yearly quantity sold is necessarily smaller than the total output. Apart from the technological improvement in cultivars, rotation and diversification also can be effective short-term adaptation tools to reduce production and price risks caused by unfavorable climate conditions or markets. A corn-soybean rotation was adopted in the modeling process for all sites, and diversification constraints were applied[7]. Equation (5) is the constraint, where the maximum acreage is set for each crop in different years based on the rotation. To provide greater flexibility in choosing the most profitable annual production bundle, these limits were not set by the current situation, but set slightly higher than their actual shares and a minimum requirement was not set. Through randomly adjusting the value of all variables subjected to all the constraints and the non-negative requirement equation (6), an optimized objective value can be estimated. In this case, some of the unknown variables such as land allocation and contract labour hours are required to be integers.

[5] A minimum of five percent of the total output for each crop will be stored for farm consumption according to historical data.
[6] This number was obtained from Centre d'études sur les coûts de production en agriculture.
[7] In the corn year, grain corn was allowed on a maximum of 80% of the total cultivated land while soybean could be grown up to 60%, and vice versa. On the other hand, a maximum of 25% and 30% of crop area could be used for wheat and barley, respectively.

CHAPTER 5
RESULTS AND DISCUSSION

5.1. RESOURCE ALLOCATION

5.1.1. Optimal Land Allocation

With 350 ha of available cropland on the representative farms for each selected site, the cultivable land is efficiently allocated to each crop to achieve the goal of maximizing profit after applying the rotation and diversification constraints. Appendix 4 presents the optimal average annual land allocation for both reference cultivar models and improved cultivar models. The results indicate that the different climate scenarios (Hot & Dry, Hot & Humid, Median, Cold & Dry, and Cold & Humid) do not cause significant differences in land use rate at each site. It is the weather conditions, i.e. with or without atmospheric CO_2 enhancement and water limitation, which makes the land utilization very sensitive. This can be illustrated with the optimal annual average land allocation by climate scenarios (Table 2). As shown in both models, while the proportion of land cultivated in St-Sébastien is consistent for the different weather conditions, the land allocation at the two other sites becomes variable. In Ste-Martine, the area of land cultivated is decreased when water is limited, especially coupled with no CO_2 enhancement. In this case, the average cultivated land only occupies 35.5 percent of the total land available. Consecutive underutilization of the land resource may lead the producer to be more vulnerable and less flexible in dealing with potential risks. The case of North Dundas is not as severe, but water limitations can result in a slight decrease in land utilization. Soybeans surpassed grain corn as the largest allocated crop under all scenarios and conditions in the three sites when considering only the reference cultivar. The second largest crop in Montérégie is barley and corn in North Dundas.

Table 2: Optimal Average Annual Land Allocation by Climate Scenario

Site	CO_2 and Water Conditions	Reference Cultivar					Improved Cultivar				
		corn	wheat	barley	soya	% of Available Area	corn	wheat	barley	soya	% of Available Area
		(in ha)									
SMT	CO2 & No Water Limit	26	7	50	180	75.0	114	55	91	74	95.4
	CO2 & Water Limit	18	3	36	127	52.3	21	6	70	156	72.6
	No CO2 & No Water Limit	30	9	49	176	75.3	126	55	93	64	96.8
	No CO2 & Water Limit	12	2	21	89	35.5	19	4	44	105	49.4
SSB	CO2 & No Water Limit	19	1	59	181	74.2	97	1	88	124	88.7
	CO2 & Water Limit	27	1	51	182	74.6	21	1	70	173	75.6
	No CO2 & No Water Limit	19	1	58	179	73.7	117	1	93	111	92.1
	No CO2 & Water Limit	29	2	48	180	73.8	28	1	64	173	76.0
D_N	CO2 & No Water Limit	110	6	0	173	82.7	108	7	1	173	82.5
	CO2 & Water Limit	98	7	0	178	80.8	95	8	2	166	77.5
	No CO2 & No Water Limit	117	5	0	170	83.5	115	7	0	170	83.5
	No CO2 & Water Limit	98	7	0	179	80.9	107	7	0	174	82.3

Note: SMT= Ste-Martine, SSB= St-Sébastien, D_N= North Dundas

The development of technological advancements, in terms of the improved cultivars, increases the proportion of land cultivated in the Montérégie. Technological change not only increases the area cultivated but also changes the crop mix. This is particularly evident in the Montérégie where the yield per hector has increased the most. Under the condition of no water limitation, the land area is almost fully cultivated in Ste-Martine and St-Sébastien due to the increase in corn and barley cultivation. Corn acreage can even surpass soybean acreage as the largest crop under this condition. However, when water is limited, soybean cultivation is still in a dominant position in helping producers reduce their losses and increase their income. Climate scenario and cultivar have little impact on the land utilization in North Dundas. This stability decreases uncertainty in the changing environment.

5.1.2. Optimal Labour Allocation

The need for labour was unequally distributed throughout the growing season. Therefore, each year was broken down into 6 periods (mostly monthly) for each growing season according to the major agricultural activities including seeding, harvesting, sales, etc. A total of 4,725 hours of labour were allocated based on the labour needs of the agricultural activities. Labour intensive activities happen in three periods, i.e. beginning of May, October and November, when seeding and harvesting takes place. In accordance with the optimal land allocation, differences exist among various scenarios, regions and technology levels, and water availability plays a more important role than the various climate scenarios, especially coupled with CO_2 enhancement. Higher land utilization results in a higher use of hired labour. In the reference cultivar model, approximately 55 percent of the total available labour hours were allocated under all scenarios and conditions in St-Sébastien, and hired labour accounts for about 35 percent of this allocation (Table 3). Labour allocation in Ste-Martine was similar to St-Sébastien's under favourable conditions where water was not limited. However, when water limitations apply, the proportion of labour employed decreased to 43-45 percent and even more significantly to 25-30 percent when there was no CO_2 enhancement. Compared with the two sites in Montérégie-west, North Dundas has a greater utilization of labour each year (63.3-73.2 percent), with approximately 40 percent of the labour being hired. Significant differences exist between conditions, with or without CO_2 enhancement and water limitation, rather than climate scenarios at this site. As expected, producers were worse off when water was limited.

Using the improved cultivars increased labour employment in Ste-Martine under all conditions. While the optimal labour utilization increased to 84 percent under favorable conditions at this site. Access to the improved cultivars increased labour utilization by approximately 10 percent under unfavorable conditions. The proportion of hired labour also increased by the same rate to approximately 35 percent. In St-Sébastien, the use of the improved cultivars increased the proportion of labour employed to 69.8-82.6% under favorable conditions, but did not make a change in labour utilization when water was limited. Improved cultivars did not bring higher labour employment in North Dundas since it remained at the same level as in the reference cultivar model. Unlike land allocation, climate scenarios can make a difference here. The Cold & Humid climate scenario was favored by all three sites under each condition.

5.2. OPTIMAL OUTPUT

The optimal crop output is largely dependent on land allocation, as well as the crop yield per unit. This is also determined by regional comparative advantage. (Table 4). According to the results from the reference cultivar model, the output of soybeans ranks first while that of wheat was the lowest in Montérégie. This corresponds to the crop allocation in the region (Table 2). Grain corn dominates in North Dundas, followed by soybean. Barley was not planted in North Dundas since the model found it to be less profitable than other alternatives. Comparing the climate scenarios, Cold & Dry was the worst for soybean production and Cold & Humid was favorable for corn. In Ste-Martine and North Dundas, having no water limitation was always favored by each crop under all scenarios. In St-Sébastien, however, slightly less corn and soybean were planted when there was no water limitation, and more barley was planted.

Table 3: Average Optimal Annual Labour Allocation for Reference and Improved Cultivar Models

	Site	CO_2 and Water Conditions	Hot & Dry				Hot & Humid				Median				Cold & Dry				Cold & Humid			
			Hired Labor	% of Total Labor	Total Labor	% of Total Available	Hired Labor	% of Total Labor	Total Labor	% of Total Available	Hired Labor	% of Total Labor	Total Labor	% of Total Available	Hired Labor	% of Total Labor	Total Labor	% of Total Available	Hired Labor	% of Total Labor	Total Labor	% of Total Available
			(in hours)																			
Ref	SMT	CO2 & No Water Limit	979	36.1	2712	57.4	939	35.9	2612	55.3	988	36.2	2732	57.8	938	35.6	2634	55.7	1004	36.2	2775	58.7
		CO2 & Water Limit	263	27.6	953	20.2	665	32.2	2064	43.7	707	33.1	2135	45.2	643	31.0	2076	43.9	723	33.8	2137	45.2
		No CO2 & No Water Limi	1013	36.7	2763	58.5	927	35.7	2597	55.0	1034	37.0	2792	59.1	923	35.6	2594	54.9	1084	37.7	2873	60.8
		No CO2 & Water Limit	387	32.7	1182	25.0	435	33.0	1320	27.9	410	32.6	1259	26.6	345	30.3	1140	24.1	464	32.2	1443	30.5
	SSB	CO2 & No Water Limit	938	35.5	2644	56.0	923	35.3	2618	55.4	953	35.8	2662	56.3	924	35.2	2622	55.5	951	35.6	2670	56.5
		CO2 & Water Limit	951	35.7	2663	56.4	929	34.9	2659	56.3	958	35.4	2703	57.2	959	35.3	2714	57.4	969	35.8	2705	57.2
		No CO2 & No Water Limi	930	35.4	2628	55.6	921	35.3	2610	55.2	950	35.7	2658	56.3	882	34.4	2565	54.3	939	35.4	2652	56.1
		No CO2 & Water Limit	938	35.5	2644	56.0	917	34.8	2632	55.7	941	35.0	2687	56.9	945	35.5	2664	56.4	950	35.4	2687	56.9
	D_N	CO2 & No Water Limit	1324	41.3	3205	67.8	1399	42.5	3288	69.6	1397	42.5	3288	69.6	1423	42.7	3335	70.6	1444	43.0	3358	71.1
		CO2 & Water Limit	1222	39.5	3094	65.5	1148	38.4	2993	63.3	1387	42.3	3276	69.3	1310	41.0	3198	67.7	1407	42.4	3319	70.2
		No CO2 & No Water Limi	1387	42.3	3276	69.3	1414	42.8	3301	69.9	1400	42.5	3294	69.7	1523	44.2	3443	72.9	1539	44.5	3460	73.2
		No CO2 & Water Limit	1174	38.6	3043	64.4	1165	38.7	3014	63.8	1343	41.5	3233	68.4	1299	40.6	3196	67.6	1452	43.1	3368	71.3
Imp	SMT	CO2 & No Water Limit	1770	45.4	3898	82.5	1623	43.7	3711	78.5	1805	45.4	3979	84.2	1768	44.6	3964	83.9	1827	45.5	4015	85.0
		CO2 & Water Limit	916	35.6	2570	54.4	856	34.1	2507	53.1	970	36.0	2692	57.0	939	35.5	2648	56.0	952	35.4	2686	56.8
		No CO2 & No Water Limi	1795	45.6	3940	83.4	1763	45.2	3901	82.6	1880	46.2	4065	86.0	1887	45.9	4110	87.0	1886	46.0	4104	86.9
		No CO2 & Water Limit	558	32.3	1729	36.6	526	31.5	1668	35.3	616	32.1	1917	40.6	560	32.7	1710	36.2	680	34.6	1968	41.7
	SSB	CO2 & No Water Limit	1488	42.5	3501	74.1	1354	41.0	3300	69.8	1585	43.5	3642	77.1	1498	42.3	3538	74.9	1622	43.6	3718	78.7
		CO2 & Water Limit	971	36.1	2689	56.9	944	35.7	2645	56.0	1009	36.7	2750	58.2	962	35.3	2722	57.6	986	36.2	2727	57.7
		No CO2 & No Water Limi	1600	42.9	3732	79.0	1424	41.2	3456	73.1	1685	44.0	3829	81.0	1679	43.5	3856	81.6	1740	44.6	3905	82.6
		No CO2 & Water Limit	964	36.1	2674	56.6	941	35.4	2660	56.3	1044	36.7	2841	60.1	1025	36.9	2778	58.8	1036	37.2	2787	59.0
	D_N	CO2 & No Water Limit	1297	40.7	3185	67.4	1407	42.8	3290	69.6	1399	42.5	3290	69.6	1417	42.7	3319	70.2	1403	42.4	3308	70.0
		CO2 & Water Limit	893	37.8	2364	50.0	1244	40.0	3110	65.8	1348	41.6	3241	68.6	1356	41.7	3254	68.9	1366	41.8	3265	69.1
		No CO2 & No Water Limi	1374	42.1	3265	69.1	1411	42.9	3291	69.7	1399	42.5	3292	69.7	1500	43.8	3421	72.4	1554	44.8	3471	73.5
		No CO2 & Water Limit	1306	41.0	3188	67.5	1775	54.7	3247	68.7	1395	42.4	3287	69.6	1398	42.4	3298	69.8	1430	42.8	3338	70.6

Table 4: Average Optimal Annual Output for Reference and Improved Cultivar Models

	Site	CO_2 and Water Conditions	Hot & Dry				Hot & Humid				Median				Cold & Dry				Cold & Humid			
			corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya
			(in tonnes)																			
Ref	SMT	CO2 & No Water Limit	270	49	218	859	105	33	329	817	265	64	244	831	138	24	304	784	336	45	236	809
		CO2 & Water Limit	62	7	42	179	67	12	166	484	117	8	149	498	136	5	130	457	206	11	120	480
		No CO2 & No Water Limit	298	55	209	719	96	31	300	693	315	61	219	698	158	43	237	656	422	45	210	671
		No CO2 & Water Limit	41	5	72	261	35	4	88	297	95	4	60	273	65	3	66	237	208	5	57	263
	SSB	CO2 & No Water Limit	127	1	246	899	82	1	268	870	154	1	241	895	94	1	263	831	168	1	233	875
		CO2 & Water Limit	143	0	177	901	129	0	183	918	199	0	151	900	215	0	154	864	205	0	160	879
		No CO2 & No Water Limit	118	0	220	756	78	1	238	735	150	0	214	755	103	0	221	686	165	0	204	733
		No CO2 & Water Limit	135	0	137	757	137	1	138	766	204	0	115	755	239	0	108	712	220	0	115	735
	D_N	CO2 & No Water Limit	928	30	0	770	1009	28	0	697	1020	29	0	778	1154	31	0	676	1170	38	0	708
		CO2 & Water Limit	723	34	0	752	636	46	0	795	935	29	0	746	923	35	0	742	1133	36	0	752
		No CO2 & No Water Limit	947	23	0	619	977	24	0	586	992	21	0	638	1212	15	0	55	1236	33	0	571
		No CO2 & Water Limit	630	28	0	675	642	27	0	694	837	28	0	660	855	26	0	651	1138	30	0	643
Imp	SMT	CO2 & No Water Limit	1516	603	1202	375	1153	598	1136	430	1621	676	1271	315	1506	569	1243	316	1699	644	1216	309
		CO2 & Water Limit	122	45	559	500	91	35	510	512	212	39	554	526	248	34	455	483	253	34	488	501
		No CO2 & No Water Limit	1544	557	1106	315	1387	485	1080	321	1710	632	1169	248	1688	572	1154	206	1814	633	1120	221
		No CO2 & Water Limit	77	28	331	311	64	23	307	314	166	25	310	338	213	23	259	275	292	24	292	296
	SSB	CO2 & No Water Limit	1124	4	1240	635	848	4	1209	665	1305	4	1274	596	1156	4	1223	569	1466	4	1168	570
		CO2 & Water Limit	145	2	670	858	98	10	630	888	201	3	661	837	231	3	565	833	208	2	613	835
		No CO2 & No Water Limit	1352	4	1157	480	1010	3	1121	529	1485	4	1197	452	1468	4	1179	412	1643	4	1101	431
		No CO2 & Water Limit	142	1	522	734	123	5	501	751	332	1	491	702	326	1	426	708	293	1	449	706
	D_N	CO2 & No Water Limit	999	53	11	961	1110	48	0	870	1133	42	0	973	1260	63	0	845	1233	66	13	891
		CO2 & Water Limit	636	62	1	587	819	61	2	812	952	56	4	883	1067	57	10	770	1064	62	11	809
		No CO2 & No Water Limit	1033	33	0	779	1069	40	0	733	1095	34	0	798	1316	42	0	693	1374	57	0	711
		No CO2 & Water Limit	854	38	0	713	945	36	0	667	981	33	0	720	1072	45	0	645	1102	51	0	663

Results from the improved cultivar model indicate that grain corn and barley production increased significantly by using the improved cultivars in the Montérégie. Having no water limitation had a significant impact on corn and barley output. The amount of wheat produced remains low under most scenarios and conditions at each site. The exception occurs in Ste-Martine, where wheat surpassed soybean as the third largest crop when you have no water limitation. In most cases, conditions with CO_2 enhancement dominate those without in the optimal average output for each crop. However, in St-Sébastien, corn cultivation was increased under the condition of no CO_2 enhancement by taking away from barley and soybean production. Using improved cultivars increased the output of corn, wheat and soybean in North Dundas in almost equal proportion. The Cold & Humid scenario would favor the production of grain corn under all conditions at all sites. While the best climate scenario for barley and soybean in the Montérégie was Hot & Dry, it was the Median scenario that favors soybean production in North Dundas. Therefore, climate change is more likely to favor barley and soybean production in Montérégie and its negative effect cannot be offset absolutely by technological development.

5.3. ECONOMIC VULNERABILITY

The average climate condition and its variability tends to change due to global warming, thus increasing the vulnerability of the agriculture sector because it relies heavily on climate variables as an input into production. On one hand, their production process needs to be consistent with the historical record and experience, which might be the result of their risk management behaviours. But this could also contribute to building into the model a rigid management situation, which will shift the focus from actually improving profitability to compliance with requirements (Andersen and Mostue 2012). On the other hand, adaptation strategies must be designed to increase both their agronomic and economic resilience against this unpredictable variability. A balance between compliance and resilience is needed. In this section, the number of years which experienced marginal reductions across the different scenarios and conditions will provide an indication of how climate change impacts the economic vulnerability of the representative farms. In addition, the participation rate in insurance programs can provide information on the optimal level at which producers should participate in insurance programs to provide a resilient strategy for each crop.

5.3.1. Vulnerability and Margin Reduction

The margin reduction is the difference between the current year's margin and the Olympic average margin of the past five years (Appendix 5). The result in Table 5 indicates that weather conditions, i.e. CO_2 concentration and water availability, have a greater impact on producers' economic vulnerability than climate scenarios. Results from the reference cultivar model indicate that producers were very vulnerable to marginal reductions under all scenarios, but at different magnitudes depending on their location and weather conditions. Generally speaking, North Dundas was the best site for producers. The results from the reference model for this site would suggest they experience fewer marginal reductions and the magnitudes were smaller. For example, losses of between 30 to 100 percent only occur in approximately 7 of the 30 years with less variability among weather conditions. It was followed by St-Sébastien and then Ste-Martine. Water resources can have a substantial effect on producers' income vulnerability. Producers at each site would suffer the largest losses when water limitations existed, particularly coupled with a lack of CO_2 enhancement. This is a serious situation in Ste-Martine, where the model would indicate that producers would suffer moderate losses (30-100% reduction) in 3 of the 30 years, but extremely large losses (>100% reduction) in 11 of 30 years. Losses of this magnitude and frequency leaves these producers vulnerable to bankruptcy.

Table 5: Numbers of Years with Margin Reduction under Optimal Decisions

Site	CO_2 and Water Conditions	Reference Cultivar				Improved Cultivar			
		<0	0-30%	30%-100%	>100%	<0	0-30%	30%-100%	>100%
SMT	CO2 & No Water Limit	15.4	8.8	5.8	0	12.6	16.2	1.2	0
	CO2 & Water Limit	13.6	3	9.4	4	14	2.8	13.2	0
	No CO2 & No Water Limit	15	7.4	7.6	0	12.8	15	2.2	0
	No CO2 & Water Limit	12.2	3.2	3.2	11.4	13	1.6	8.4	7
SSB	CO2 & No Water Limit	16.6	6	7.4	0	14.2	14.2	1.6	0
	CO2 & Water Limit	16.6	4.8	8.6	0	17	9.2	3.8	0
	No CO2 & No Water Limit	17	4.4	8.6	0	14.6	12.6	2.8	0
	No CO2 & Water Limit	15.8	5	9.2	0	17	6.2	6.8	0
D_N	CO2 & No Water Limit	16.2	7.6	6.2	0	16.2	9.8	4	0
	CO2 & Water Limit	16.2	6.6	7.2	0	15.2	7.6	7.2	0
	No CO2 & No Water Limit	16	7	7	0	16.2	8.6	5.2	0
	No CO2 & Water Limit	16.2	6.2	7.6	0	16.2	7.2	6.6	0

Adopting the improved cultivar does not guarantee that the improved cultivar will always be selected in all cases, or the possibility of suffering large losses will be eliminated, but it does help decrease the magnitude and frequency under all scenarios. It should be noted that this technical improvement has enhanced the resilience of all producers to climate change; the magnitude of this resiliency varies with availability and CO_2 enhancement. Under favorable conditions, where CO_2 and water were adequate, the producer can be much better off when they adopt the improved cultivars. Technological change, i.e. cultivar improvements, can ameliorate some of the negative effects of adverse weather conditions, i.e. no CO_2 enhancement and water limitations, and the different climate scenarios, thus building resilience in the farming community. The large losses (>100% reduction) in Ste-Martine still occur when there was negative weather conditions. Farms in the region were susceptible to bankruptcy if these large losses occur in successive years.

5.3.2. Insurance Participation Rate

The coverage rate of the AgriStability insurance program was used as an indicator of the impact that climate change had on producers' margins. Producers who have pessimistic expectation on their production and thus margins might change their insurance behaviour as it relates to weather conditions or uncontrollable natural disasters. As a result, producers may want to adopt different risk management tools to avoid this loss. The Individual Crop Insurance (ICI) or Production Insurance (PI) plans are often considered as production safety programs when different coverage levels are being selected for various crops and regions (Lehmann et al. 2013). Thus producers' enrolment level in these two programs can be considered as an indicator of how they perceive the risk of climate change. The adaptation of different risk management tools is an institutional strategy to address climate change. Table 6 provides the optimal average percentage of annual cultivated land enrolled in either ICI or PI programs for each site and condition in terms of both reference and improved cultivar models. The higher the participation proportion, the more variable the potential yield is.

The results from both the reference and improved cultivar models would indicate that the optimal choice for producers for all sites, scenarios and conditions was to be covered by either the maximum coverage or not enroll in these insurance programs. Thus, this study only compares the proportion of land which is insured with the maximum coverage. In the reference cultivar model, wheat was the crop that had the most coverage and the highest participation proportion in these production safety insurance programs. In North Dundas, the portion participating can be as high as 90 percent. This would indicate that wheat yield per ha was subject to wide variations from year to year in the future under all scenarios. Barley and soybeans were insured less in the Montérégie, particularly when water limitations did not apply. Again, producers tended to insure more for each crop when there were water limitations, especially when CO_2 enhancement was also absent. It is interesting to note that a higher average participation proportion can be found in the Hot & Dry scenario for the Montérégie region, and decreases as the scenarios move towards the Median and finally Cold & Dry. The opposite results were found in North Dundas. From a regional perspective, North Dundas has the highest participation rate for all crops except barley, which was not very profitable to plant in this area, followed by Ste-Martine, and St-Sébastien at a much lower level under all conditions.

In the case of the improved cultivar model, crop insurance participation was much lower for all sites and scenarios. Wheat participation had decreased by approximately 45% in Montérégie and 80% in North Dundas, while barley insurance participation increased by approximately 10% in Montérégie under all scenarios and conditions. Contrary to the results with the reference cultivar model, but in accordance with the situation in North Dundas, the highest participation can be found with the Cold & Dry scenario and decreases towards the Hot & Dry scenario in Montérégie. CO_2 alone does not play an important role when the improved cultivar was used, but its absence can exacerbate the vulnerable conditions when water was not available. As a C_4 crop, grain corn does not have better performance for any site or cultivar under the Hot & Dry scenario as was expected. Looking at the economic vulnerability analysis, producers who were economically vulnerable, from either climate risks or market shocks, tended to take precautionary measures by increasing their insurance participation, so as to protect themselves from shocks or benefits more from potential opportunities.

Table 6: Participation in the Production Safety Insurance Programs by Crop
(in % of annual average cultivation land enrolled)

	Site	CO2 and Water Conditions	Hot & Dry				Hot & Humid				Median				Cold & Dry				Cold & Humid			
			corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya
Ref	SMT	CO2 & No Water Limit	0.0%	83.3%	0.0%	0.0%	0.0%	79.1%	0.0%	0.0%	0.0%	87.4%	0.0%	0.0%	0.0%	72.3%	0.0%	0.0%	0.0%	82.4%	0.0%	0.0%
		CO2 & Water Limit	45.0%	93.2%	35.5%	36.7%	9.2%	71.6%	26.4%	30.2%	28.1%	63.0%	26.9%	29.3%	27.4%	61.4%	33.7%	27.6%	24.0%	73.8%	21.3%	26.9%
		No CO2 & No Water Limit	0.0%	86.0%	0.0%	0.0%	18.3%	79.0%	0.0%	0.0%	0.0%	87.2%	0.0%	0.0%	0.0%	84.9%	0.0%	0.0%	0.0%	83.3%	0.0%	0.0%
		No CO2 & Water Limit	91.9%	66.1%	22.4%	18.7%	66.8%	64.3%	27.2%	20.6%	26.2%	63.2%	18.5%	19.8%	33.8%	53.1%	24.8%	17.9%	24.5%	64.4%	0.2%	25.5%
	SSB	CO2 & No Water Limit	14.2%	16.1%	0.0%	0.0%	12.7%	17.1%	0.0%	0.0%	8.3%	13.3%	0.0%	3.0%	6.1%	17.7%	0.0%	3.0%	5.1%	13.3%	3.0%	0.0%
		CO2 & Water Limit	26.4%	50.0%	27.3%	0.0%	31.5%	45.2%	24.8%	0.0%	25.5%	50.0%	32.4%	3.2%	20.0%	46.3%	8.9%	0.0%	11.1%	46.3%	11.6%	0.0%
		No CO2 & No Water Limit	15.0%	16.7%	0.0%	0.0%	24.9%	11.1%	0.0%	0.0%	8.0%	12.9%	0.0%	0.0%	10.7%	18.2%	0.0%	3.1%	4.2%	16.7%	3.0%	0.0%
		No CO2 & Water Limit	36.7%	50.0%	33.7%	0.0%	26.8%	41.7%	28.2%	0.0%	28.4%	52.8%	30.0%	0.0%	7.1%	51.0%	13.8%	0.0%	9.4%	52.9%	11.8%	0.0%
	D_N	CO2 & No Water Limit	18.2%	90.9%	-	36.7%	19.6%	88.8%	-	37.6%	25.1%	88.8%	-	37.1%	27.6%	90.9%	-	37.5%	22.9%	91.6%	-	36.5%
		CO2 & Water Limit	20.5%	90.7%	-	38.2%	19.7%	90.3%	-	38.5%	26.7%	89.1%	-	37.1%	29.5%	91.5%	-	37.5%	23.0%	92.0%	-	36.5%
		No CO2 & No Water Limit	17.0%	89.6%	-	36.8%	22.2%	87.8%	-	37.4%	25.0%	88.2%	-	37.1%	27.9%	84.6%	-	37.4%	24.2%	91.0%	-	36.4%
		No CO2 & Water Limit	21.5%	87.9%	-	39.1%	19.6%	89.4%	-	38.5%	28.1%	89.3%	-	37.1%	29.6%	89.1%	-	37.5%	23.5%	90.7%	-	36.4%
Imp	SMT	CO2 & No Water Limit	3.0%	0.0%	8.5%	0.0%	4.6%	0.0%	8.7%	0.0%	2.8%	0.0%	4.2%	0.0%	2.9%	0.0%	10.7%	0.1%	2.7%	0.0%	4.2%	0.0%
		CO2 & Water Limit	5.3%	39.6%	38.9%	28.6%	7.4%	22.4%	34.5%	22.4%	13.4%	19.5%	45.0%	31.1%	0.1%	8.1%	41.5%	28.8%	3.0%	9.2%	46.0%	29.0%
		No CO2 & No Water Limit	2.9%	0.0%	8.5%	0.0%	0.0%	0.0%	11.6%	0.0%	2.6%	0.0%	4.4%	0.0%	2.6%	0.0%	10.6%	1.4%	2.5%	0.0%	4.1%	0.0%
		No CO2 & Water Limit	12.2%	33.3%	42.6%	26.7%	0.0%	9.0%	37.7%	2.7%	10.7%	8.2%	36.0%	30.2%	0.3%	9.9%	40.1%	30.8%	0.0%	9.1%	40.2%	30.4%
	SSB	CO2 & No Water Limit	0.0%	3.3%	8.1%	0.0%	0.0%	7.3%	17.1%	0.0%	0.0%	0.0%	10.9%	0.0%	0.0%	0.0%	13.5%	0.0%	0.0%	0.0%	11.0%	0.0%
		CO2 & Water Limit	14.8%	34.6%	27.2%	-	14.1%	11.8%	28.1%	0.0%	15.6%	27.3%	28.3%	0.0%	2.5%	23.5%	27.0%	0.0%	4.2%	29.6%	35.0%	-
		No CO2 & No Water Limit	0.0%	3.3%	10.1%	0.0%	1.6%	3.0%	16.3%	0.0%	0.0%	0.0%	13.7%	0.0%	0.0%	0.0%	13.5%	0.2%	0.0%	3.3%	13.0%	0.0%
		No CO2 & Water Limit	19.5%	40.0%	28.7%	-	11.6%	22.2%	26.8%	0.0%	10.1%	44.4%	33.7%	0.0%	5.3%	42.9%	30.8%	0.0%	5.7%	46.4%	38.6%	0.0%
	D_N	CO2 & No Water Limit	15.4%	8.3%	0.0%	36.7%	16.9%	7.3%	0.0%	37.2%	24.9%	10.0%	-	37.1%	23.4%	6.8%	-	37.5%	20.0%	6.8%	0.0%	36.5%
		CO2 & Water Limit	6.5%	6.2%	44.4%	36.3%	15.2%	7.4%	0.0%	37.8%	26.2%	9.1%	0.0%	36.9%	23.9%	7.3%	0.0%	37.5%	-	6.7%	0.0%	37.1%
		No CO2 & No Water Limit	14.6%	9.7%	-	36.6%	17.0%	7.0%	-	37.4%	25.1%	10.6%	-	37.1%	24.7%	8.1%	-	37.7%	21.2%	7.6%	-	36.2%
		No CO2 & Water Limit	15.3%	6.2%	-	36.8%	16.0%	6.3%	-	21.5%	25.0%	8.0%	-	37.1%	23.9%	5.2%	-	36.2%	5.3%	6.1%	-	36.8%

Note: -- indicates that the crop was not grown. (Barley was not very profitable in North Dundas when compared to other crops)

5.4. EFFECTS OF INSTITUTIONAL ADAPTATION

It is the complex interaction among a great many climatic and institutional factors that ultimately influences agricultural production and financial management. Most of the research in Canada is on the potential impact of crop yields and agricultural production, however, the role of humans in the decision-making process should not be neglected (Bryant et al. 2000). From this point of view, the adaptation of agriculture to climate variability is multifaceted and should not only focus its attention on technical and economic aspects, but also on institutional strategies.

5.4.1. Net Institutional Benefits

It was assumed that the institutional policies of these insurance programs, including the coverage, premium and compensation rate, remain unchanged over the planning period of the model. Since only one kind of compensation from either ASRA (or RMP) or AgriStability, whichever is higher, can be obtained by the producer, it is worth comparing the net benefits brought by them. The results for the reference and improved cultivar models are presented in Table 7. The results should be interpreted with caution since the compensation happens only after the losses have taken place. This is especially the case with AgriStability, since government payments occur only when there exists a margin reduction larger than 30 percent. The higher the net benefit observed, the larger the loss is. The specific amounts of net benefit coming from the insurance programs is not what the producer will actually receive, since these programs are subject to change periodically. Recently, a large number of changes have occurred in a relatively short time period. As a result, they might be better used to give us an indication concerning margin reductions, or the relationship between stabilised income and market crop prices.

Table 7: Average Optimal Net Benefits by Insurance Program

	Site	CO2 and Water Conditions	Hot & Dry			Hot & Humid			Median			Cold & Dry			Cold & Humid		
			AgriStability	ASRA	AgriInvest	AgriStability	ASRA	AgriInvest	AgriStability	ASRA	AgriInvest	AgriStability	ASRA	AgriInvest	AgriStability	ASRA	AgriInvest
			(in dollars)														
Ref	SMT	CO2 & No Water Limit	9349.0	3177.2	8870.5	9308.1	3299.0	8142.5	9837.0	2392.0	8611.4	11507.0	3707.5	7355.5	10113.3	1817.7	8361.4
		CO2 & Water Limit	14904.4	10422.3	2116.3	18280.6	14498.5	3813.5	20252.1	12786.4	4017.8	16249.7	14862.7	3238.6	20398.3	11795.4	3791.4
		No CO2 & No Water Limit	10405.9	4328.1	6309.9	10046.5	3910.6	5637.5	10894.6	5251.7	6077.2	11812.1	3464.5	5029.1	11518.6	2834.1	5879.5
		No CO2 & Water Limit	12490.4	11730.7	1766.8	14717.2	14467.8	2051.8	15648.6	12568.1	1927.6	10148.9	11994.3	1390.3	14821.4	15440.8	1874.2
	SSB	CO2 & No Water Limit	12395.0	13023.4	8592.3	14756.0	13174.5	8051.1	13220.4	12701.9	8590.1	4258.1	12324.3	7468.8	14464.9	11201.4	8219.3
		CO2 & Water Limit	12454.2	21151.5	8195.4	13508.2	21402.7	8566.6	13653.2	21768.1	8162.2	14146.7	22548.4	7315.9	14038.6	21381.5	7808.3
		No CO2 & No Water Limit	12325.8	15226.9	5742.3	13532.9	15173.4	5302.7	12759.8	15395.7	5732.4	13039.1	15224.9	4796.3	13521.0	13900.0	5421.0
		No CO2 & Water Limit	12961.4	26004.7	5271.1	14336.4	26776.5	5515.4	13886.4	26629.3	5283.2	16473.8	27449.2	4514.9	14048.4	26629.3	4906.6
	D_N	CO2 & No Water Limit	3135.0	-199.6	13240.7	6576.0	-233.1	11743.9	3936.3	-182.9	13969.3	2288.6	-239.8	12659.2	4406.5	-216.4	13337.2
		CO2 & Water Limit	4489.1	-215.9	11697.9	7097.7	-197.1	12192.6	4387.2	-204.6	12559.0	4075.0	-212.2	12772.2	4516.3	-193.3	14073.4
		No CO2 & No Water Limit	5168.5	-283.3	9897.6	6659.4	-300.0	9200.1	5623.6	-269.9	10710.3	3365.6	-306.7	10074.4	6316.8	-293.3	10540.9
		No CO2 & Water Limit	6561.3	-264.9	9498.3	8256.7	-257.4	9860.8	5473.2	-261.2	10119.2	5880.7	-268.7	10222.0	5832.4	-257.4	11583.6
Imp	SMT	CO2 & No Water Limit	-543.3	-2166.7	18040.0	-477.5	-2783.4	16298.6	142.0	-3008.2	18384.7	631.0	2326.2	16512.2	-1070.8	-3087.9	17893.4
		CO2 & Water Limit	15538.2	23747.6	6531.5	11559.5	21196.4	6024.8	13302.2	14303.3	6855.5	10243.6	18017.0	5331.4	13741.5	17858.4	5993.3
		No CO2 & No Water Limit	56.4	-1748.4	15645.6	-707.4	-2122.5	13723.1	688.0	-3013.8	16031.1	2303.3	2317.1	14360.0	229.7	-3126.5	15618.7
		No CO2 & Water Limit	19206.6	12828.3	3371.9	17129.7	11549.1	3166.2	19772.7	13029.9	3719.8	14359.6	6199.4	2849.7	17525.8	9279.5	3387.7
	SSB	CO2 & No Water Limit	537.2	-1820.3	15932.3	959.2	-1160.7	14924.9	-306.3	-1623.7	16010.0	280.2	-22.6	15199.3	-694.3	-1804.7	15710.7
		CO2 & Water Limit	1461.9	4020.4	11474.7	1288.9	4757.7	11559.8	2058.8	7232.3	11275.0	1411.3	1840.0	10329.4	2040.3	2539.5	10870.8
		No CO2 & No Water Limit	732.7	-1996.1	13110.7	2856.3	-746.7	12070.3	308.7	449.0	13258.0	429.3	30.9	12411.4	109.0	-1911.6	13036.3
		No CO2 & Water Limit	3234.3	7136.9	8001.8	2295.0	6864.2	7959.3	4174.8	10480.4	7950.1	5508.3	4045.5	7254.0	4414.9	5482.7	7519.7
	D_N	CO2 & No Water Limit	1068.3	4322.1	17986.2	3933.3	5879.7	16152.2	1808.9	5165.9	18882.1	1314.4	5082.2	17157.0	2141.6	4135.2	18027.3
		CO2 & Water Limit	26739.1	6622.4	11341.3	6354.0	8669.5	13445.5	2615.3	7463.9	15796.0	2658.2	7536.8	14273.6	4074.2	5550.3	15234.3
		No CO2 & No Water Limit	2435.7	10973.2	13850.5	4752.0	13360.2	13001.8	3426.4	12075.4	14852.1	1918.3	9651.9	13924.5	3132.9	8169.9	14515.3
		No CO2 & Water Limit	4520.4	16132.1	11356.8	6877.3	17122.6	10697.4	4594.4	16374.7	12161.8	3369.6	13608.3	11366.7	5187.4	12153.3	11944.9

The results from the reference cultivar model indicate that water limitation was the main driver for insurance compensations. Water limitations put producers into a very vulnerable situation economically. In Ste-Martine, the Cold & Dry scenario was the worst scenario for producers to be involved in agricultural production under favorable conditions where water was available. With water limitation, the Median scenario would surpass the Cold & Dry scenario as the most unfavorable scenario at this site. A similar situation can be observed in St-Sébastien where the top two worst scenarios were Hot & Humid and Median. On average, producers at this site were compensated by the ASRA insurance program due to the increased cost of production and fluctuating crop prices. Agriculture activity in North Dundas had a much better performance with an average negative RMP benefit. AgriStability compensation was higher under the Hot & Humid scenario. As climate change heads to a warmer future, it might favor Ste-Martine more than St-Sébastien or North Dundas.

In the Improved Cultivar model, water limitation was still a problem for producers in St-Sébastien, but they were much better off and obtained much less compensation from either ASRA or AgriStability. In Ste-Martine, producers participating in these two insurance programs had a balance of payment in the long run under favorable conditions. When a water limitation was applied, however, they received more compensation when the improved cultivar was planted. A similar situation was found in North Dundas. This again confirms that climate scenarios and weather conditions, which were reflected in variable yields, were not the only factors contributing to producers' economic vulnerability. Economic variables, including input costs and market prices, individual insurance portfolios and their interaction can all contribute to a producer' vulnerability or their flexibility to adjust to climate change.

5.4.2. Adaptations at Different Levels

The optimal net benefit that the producer could obtain from each insurance program separately was investigated in the subsection above, however, this study also investigated how these programs performed either individually or cooperatively on farmers' net returns from their agricultural activities. The aggregation of these four types of insurance programs does not mean that the compensation paid would be equal to the sum of all these net benefits after registration. However, as stated previously, the producer could only benefit from one of ASRA (or RMP) and AgriStability, whichever had the higher net benefit. The compensation from these two programs also assists producers' in their ability to contribute more to their saving accounts in the AgriInvest program. Table 8 investigates how the adoption of different levels of coverage contribute to an improvement in a producer's net return in all scenarios for both the reference and improved cultivar models respectively.

The crop production safety program, i.e. the Individual Crop Insurance program and the Production Insurance program, has been incorporated into the economic modelling process by including the premium in the cost of production; it is the adoption of the other three insurance programs that are investigated. The first column of each group, $Adapt^1$, stands for the average annual net return when all ASRA (or RMP), AgriStability and AgriInvest were included. $Adapt^2$ excludes the involvement of AgriInvest and $Adapt^3$ represents the net return when only ASRA is used. The last column of each group indicates the average net return that can be obtained over 30 years if the producer participates in none of the insurance programs. For all sites, scenarios, conditions and cultivars, the highest net return can be found when the producer adopts all of the financial risk management tools in the study, particularly when AgriInvest was involved. It was also advantageous to register for both AgriStability and ASRA (RMP) insurance programs so as to get the higher compensation, since differences exist, even though they were not significant. CO_2 enhancement with no water limitation would again be the best condition. In this case, the optimal average annual net returns from agricultural activities were the highest in both models. In the reference cultivar model, the highest annual net return was found with the Hot & Dry scenario for producers in Ste-Martine without water limitation, while the Median scenario would be preferred if water was limited. But large differences exist mainly between weather conditions rather than climate scenarios. This was the same case for St-Sébastien, farm performance was only slightly better in the Hot & Dry and Median scenarios, but CO_2 enhancement played an essential role that resulted in an approximate doubling of the annual net return. This corresponds to the situation in North Dundas, where CO_2 enhancement can improve the operation performance more than any other situation. The Median and Cold & Humid scenarios provided the highest net returns to producers at this site if the reference cultivar model was used. The results indicate that farming in North Dundas was more profitable than in Montérégie, however, since the site models used different methods to estimate the cost of production, for example a different array of variable costs. Therefore, comparisons between net returns at different sites need to be interpreted with care.

Using the improved cultivar model can substantially increase farm net returns for all sites, scenarios and conditions. In Ste-Martine, the results from the improved cultivar model indicates that the net returns were almost doubled under all conditions, but producers were still financially vulnerable in conditions where water was limited. CO_2 enhancement and the climate scenarios play a less important role at this site. When all financial risk management tools were applied, the optimal average net farm return under the most favorable conditions, no water limitation combined with CO_2 enhancement, varies from \$461,814.52 under the Median scenario to \$410,978.17 under the Hot & Humid scenario. However, if water was limited and CO_2 enhancement was not available, it can be as low as $76,853.63 under the Cold & Dry scenario even when the farm business was involved with all the insurance programs. Although the Hot & Dry scenario was not the best scenario for Ste-Martine, it remains more favorable than the others. The financial performance of the agricultural activities in St-Sébastien and North Dundas were similar when using the improved cultivar model. CO_2 was no longer the essential influencing factor at these two sites, but water availability was. The optimal average net returns were similar at Ste-Martine under the condition of no water limitation. The Median scenario was again the best scenario followed by Hot & Dry, and Cold & Dry was the worst. Under unfavorable conditions, the net return that a producer in St-Sébastien could obtain every year was greater than those in Ste-Martine. It was approximately $200,000 in St-Sébastien and $280,000 in North Dundas.

In both the reference and improved cultivar models, financial risk management strategies, such as insurance, can only help cushion the impact of climate change or market risks faced by the producers. These programs cannot eliminate the losses, especially as a medium-term or long-term adaptation option. Even though producers in the worst situation, such as producers in Ste-Martine under water limitation, can get the most benefit from insurance programs every year over the planning horizon, a sound market with a transparent and credible system, will decrease these benefits over time.

Table 8: Average Annual Net Returns with and without Adaptation

	Site	CO2 and Water Conditions	Hot & Dry				Hot & Humid				Median				Cold & Dry				Cold & Humid			
			Adapt[1]	Adapt[2]	Adapt[3]	No Adapt	Adapt[1]	Adapt[2]	Adapt[3]	No Adapt	Adapt[1]	Adapt[2]	Adapt[3]	No Adapt	Adapt[1]	Adapt[2]	Adapt[3]	No Adapt	Adapt[1]	Adapt[2]	Adapt[3]	No Adapt
			(in thousands of dollars)																			
Ref	SMT	CO2 & No Water Limit	224.0	215.1	213.5	210.1	207.1	198.9	196.7	193.5	219.3	210.7	207.9	205.5	187.5	180.2	177.7	174.3	213.1	204.7	201.8	200.1
		CO2 & Water Limit	39.5	37.4	29.2	19.0	98.4	94.6	84.7	70.4	104.6	100.6	89.5	76.9	84.3	81.0	73.6	58.7	103.7	99.9	86.9	75.3
		No CO2 & No Water Limit	159.3	153.0	150.0	145.4	143.3	137.6	134.6	130.9	154.6	148.5	144.9	139.6	130.1	125.0	119.8	116.4	150.2	144.4	140.1	137.3
		No CO2 & Water Limit	47.0	45.2	38.5	27.2	56.0	54.0	45.5	31.3	54.0	52.1	42.3	30.1	36.7	35.3	30.9	19.1	50.2	48.3	39.5	24.3
	SSB	CO2 & No Water Limit	223.1	214.5	212.9	199.9	210.3	202.2	199.8	186.9	223.5	214.9	212.4	200.0	188.4	180.9	179.5	167.4	214.4	206.1	203.2	192.3
		CO2 & Water Limit	210.8	202.6	202.2	181.1	218.1	209.5	209.1	187.8	209.7	201.5	201.0	179.1	191.6	184.3	183.9	161.5	202.0	194.2	193.1	171.7
		No CO2 & No Water Limit	148.8	143.1	141.4	126.2	137.8	132.5	130.7	115.5	149.1	143.3	140.9	125.7	120.8	116.0	113.6	98.5	141.5	136.1	133.2	119.5
		No CO2 & Water Limit	134.3	129.0	128.7	102.7	140.3	134.8	133.8	107.1	133.8	128.5	128.5	101.6	119.3	114.8	113.2	86.0	126.1	121.2	120.5	93.7
	D_N	CO2 & No Water Limit	332.8	319.5	314.7	315.4	299.2	287.4	279.2	279.9	350.0	336.0	330.4	331.1	319.5	306.8	302.8	303.6	340.4	327.0	321.0	321.7
		CO2 & Water Limit	293.7	282.0	275.9	276.6	309.5	297.3	288.5	289.2	314.6	302.0	296.0	296.7	322.7	309.9	304.2	304.9	359.0	345.0	338.8	339.5
		No CO2 & No Water Limit	249.5	239.6	232.7	233.5	234.6	225.4	216.9	217.8	269.0	258.3	250.9	251.7	254.8	244.7	239.6	240.5	271.3	260.8	252.7	253.6
		No CO2 & Water Limit	239.4	229.9	221.6	222.4	251.2	241.4	231.4	232.2	253.7	243.6	236.4	237.2	259.2	249.0	241.4	242.2	296.9	285.3	277.8	278.6
Imp	SMT	CO2 & No Water Limit	452.6	434.6	432.2	434.8	411.0	394.7	392.5	395.9	461.8	443.4	440.3	443.7	416.2	399.7	396.6	394.6	448.4	430.6	428.5	432.0
		CO2 & Water Limit	162.3	155.7	147.8	124.4	147.0	141.0	136.9	116.1	171.2	164.4	156.0	142.1	134.4	129.0	122.7	105.0	152.5	146.5	138.2	120.7
		No CO2 & No Water Limit	390.7	375.1	372.1	374.2	344.2	330.4	328.6	331.1	401.1	385.1	381.4	384.8	361.4	347.1	342.0	340.1	390.5	374.9	371.5	375.1
		No CO2 & Water Limit	92.4	89.0	77.5	64.5	86.9	83.7	73.5	61.7	97.0	93.2	80.6	67.4	76.9	74.0	61.2	55.2	92.1	88.7	74.1	64.6
	SSB	CO2 & No Water Limit	411.5	395.6	393.0	395.2	386.5	371.6	369.1	370.6	411.6	395.5	393.7	395.7	383.1	367.9	365.6	366.0	403.2	387.5	386.2	388.4
		CO2 & Water Limit	298.0	286.6	284.5	280.8	298.6	287.1	285.5	281.0	293.2	281.9	279.8	272.9	269.7	259.3	257.5	256.0	281.6	270.8	268.5	266.3
		No CO2 & No Water Limit	337.3	324.2	321.4	323.8	312.9	300.8	297.8	298.8	339.4	326.1	323.9	323.9	312.6	300.2	298.1	298.4	333.6	320.6	318.5	320.9
		No CO2 & Water Limit	207.9	199.9	197.1	190.2	205.3	197.4	195.9	189.3	205.1	197.2	195.5	185.3	190.9	183.6	179.7	176.0	194.7	187.2	184.6	179.4
	D_N	CO2 & No Water Limit	451.2	433.2	431.0	426.9	407.5	391.3	387.3	381.7	471.5	452.7	450.1	445.2	433.6	416.5	413.0	408.2	457.2	439.2	436.0	432.3
		CO2 & Water Limit	280.9	269.6	243.5	237.2	338.1	324.7	320.1	311.6	393.8	378.0	375.0	367.7	359.6	345.3	341.4	334.1	386.6	371.4	366.6	361.4
		No CO2 & No Water Limit	346.1	332.2	329.6	318.7	327.2	314.2	310.3	297.1	369.6	354.8	351.7	339.7	351.0	337.1	334.3	324.7	369.1	354.6	350.7	342.7
		No CO2 & Water Limit	282.9	271.6	267.9	251.8	268.6	257.9	253.0	236.0	301.8	289.6	286.1	269.8	284.9	273.5	270.2	256.7	302.5	290.6	286.4	274.3

5.4.3. Potential Income Improvement

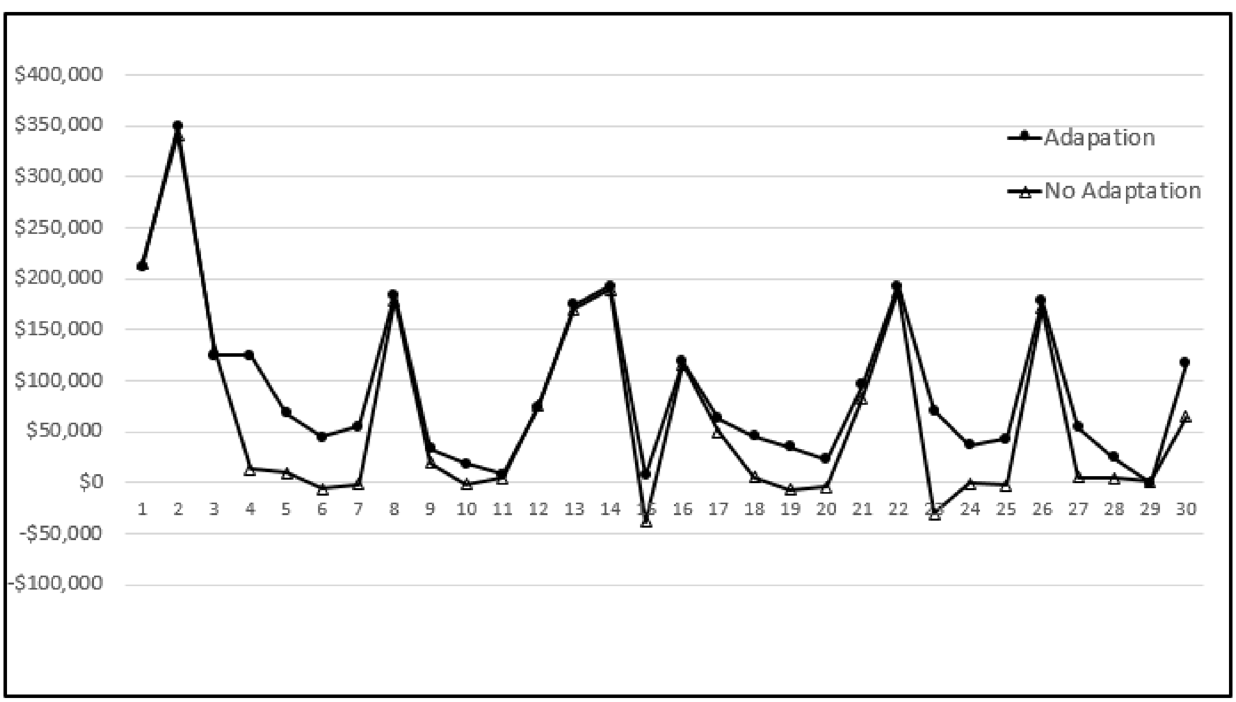
Adaptation to climate change is important not only to maintain and stabilize net farm returns, but also to provide an opportunity to increase producers' returns. Table 7 presents both the largest and least potential income improvement that could take place when adaptation strategies were applied under each condition. According to the results, all farm operations can benefit from financial risk management tools such as insurance programs, but to a different extent. Higher benefits from risk management tools can be observed when water limitations apply, and a lack of CO_2 enhancement would exacerbate this situation. Differences in the average annual potential income improvement was quite small across scenarios, except for Ste-Martine, which can possibly benefit by 106.3% under unfavorable conditions in the Cold & Humid scenario and 73.1% in the Hot & Dry scenario (using the reference cultivar model). Some general observations can be made about the climate scenarios, even though it was water availability that was critical in determining a producers' potential benefit from the insurance programs. For instance, sites in the Montérégie could benefit more from the insurance programs with the Cold & Dry or Median scenarios, while producers in North Dundas can take advantage from these strategies in the Hot & Humid scenario.

Table 9: Average Annual Potential Income Improvement, 2010-2039

	CO2 & No Water Limit	CO2 & Water Limit	No CO2 & No Water Limit	No CO2 & Water Limit
Reference Cultivar				
SMT	6.5%(C&H)-7.6%(C&D)	36.0%&(M)-108.1%(H&D)	9.4%(H&H)-11.7%(C&D)	73.1%(H&D)-106.3%(C&H)
SSB	11.5%(C&H)-12.5%(H&H)	16.1%(H&H)-18.6%(C&D)	17.9%(H&D)-22.6%(C&D)	30.8%(H&D)-38.8%(C&D)
D_N	5.2%(C&D)-6.9%(H&H)	5.8%(C&H)-7.0%(H&H)	6.0%(C&D)-7.7%(H&H)	6.6%(C&H)-8.2%(H&H)
Improved Cultivar				
SMT	3.8%(C&H)-5.8%(C&D)	20.5%(M)-30.4%(H&D)	3.9%(H&H)-6.3%(C&D)	39.3%(C&D)-43.9%(M)
SSB	3.8%(C&H)-4.7%(C&D)	5.3%(C&D)-7.5%(M)	4.0%(C&H)-4.8%(M)	8.5%(H&H)-10.7%(M)
D_N	5.7%(H&D)-6.8%(H&H)	7.0%(C&H)-18.5%(H&D)	7.7%(C&H)-10.1%(H&H)	10.3%(C&H)-13.8%(H&H)

In previous sections, results focusing on the average situations indicated that vulnerability can be significantly reduced by adopting technology development and getting involved with risk management tools. These institutional adaptation strategies play an important role in stabilizing the net farm income under all scenarios. Taking one of the worst scenarios from the Improved Cultivar model as an example (Figure 6), the effect of these institutional adaptations on annual net farm income can be evaluated over time. Even though the difference was very small, producers generally benefit more from the adaptation strategies in the first period and less in the final period. This occurs because insurance institutions will adjust the premium rate every year according to the producer's previous performance, so as to be actuarially sound in the long run. Farms with consecutive bad performances may be either no longer qualified for the insurance program or suffering very high premium rates. However, these financial risk management tools are still necessary to cushion large margin reductions.

Figure 4: The Effect of Institutional Adaptation Strategies on Periodical Net Farm Income
---- Ste-Martine_ Cold & Humid_ No CO2_Water Limit_ Improved Cultivar, 2010-2039



CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

This study assessed the potential economic impact of climate change on farm businesses in Montérégie west and eastern Ontario by integrating output from a climate modelling process and crop biophysical performance model with an economic model. Representative farms were selected in Ste-Martine, St-Sébastien and North Dundas, and the regional crop prices, cost of production, as well as labour employment were modelled in a Mixed Integer Dynamic Linear Programming (MIDLP) model. The planning horizon was from 2010 to 2039. Five climate scenarios (Hot & Dry, Hot & Humid, Median, Cold & Dry, Cold & Humid), four weather conditions (with or without CO_2 enhancement and water limitation), as well as four major field crops (corn, wheat, barley and soybean) were selected to address how the various climate scenario and weather conditions would influence producers' resource allocation decisions, economic vulnerability and financial risk management strategies.

Three different levels of approach were accounted for in order to maximize producers' annual net return. At the farm level, producers were able to determine how to allocate their limited resources and undertake farm management strategies. Apart from the reference cultivar, farmers were able to adopt improved cultivars over the planning horizon as a result of projected technology development, which were modified crop varieties better suited to the changing climate. The annual crop yields were simulated using DSSAT Cropping System Model by inputting detailed agricultural activity parameters under all scenarios and conditions at all sites. Economic factors at the market level, such as crop prices and cost of production, were projected into the future using Crystal Ball's CB Predictor (v.11.1.2.2) and Monte Carlo (MC) simulations. At the institutional level, insurance programs in both provinces were available for producers to register. The Individual Crop Insurance and Production Insurance programs are production safety programs which are used to cover production losses and yield reductions caused by uncontrollable natural perils. AgriStability covers margin declines caused by production losses, increased input costs or variable market conditions. Farm Income Stabilization Insurance (ASRA) and Risk Management Program (RMP) aim at helping producers manage market risks, such as fluctuating costs and crop prices. In addition, the AgriInvest program offers producers a saving account which benefits them by providing matching government contributions and interest on their deposits over time.

The results from this study indicate that producers' economic vulnerability varied by weather condition and site, while alternative climate scenarios played only a small role in a producer's economic vulnerability. Producers at all sites tend to have large decreases in net farm income, or even extremely large reductions, when water limitation occurred. Economic vulnerability, i.e. reductions in net farm income, were even larger when water limitations were coupled with no CO_2 enhancement. Adopting the improved cultivar does not necessarily increase the number of years of net farm income increases. However, it can significantly reduce the magnitude and frequency of large loses, and as a result, producers' are less economic vulnerable to climate change, especially for those producers in St-Martine.

Farm resource allocation, sales and storage, and net returns were dependent on the various climate scenarios and weather conditions. For example, in the reference cultivar model, Ste-Martine would have more soybean output in the Hot & Dry scenario, but would produce more corn in the Cold & Humid scenario under favorable condition, with CO_2 enhancement but no water limitation. Under unfavorable conditions, the Median scenario would be preferred for both crops at this site. With the improved cultivar model, the highest insurance participation proportion was for barley and was found in the Cold & Humid scenario if water was limited, and in the Hot & Humid scenario if not. Water availability plays an essential role in farm production and water limitation tend to result in producers suffering severe financial losses, particularly when coupled with no CO_2 enhancement. For example, the land cultivation proportions were more affected by different weather conditions, rather than by climate scenarios. A lower rate of land use can be observed when there was a water limitation and this situation can be exacerbated by the absence of CO_2 enhancement, particularly in Ste-Martine. This indicates that producers tend to be more vulnerable and less resilient under these conditions. In addition, climate change which was predicted to have a warming tendency will favor producers in Ste-Martine more than those from other sites, if adequate water was available. But if water was limited, Ste-Martine will be extremely vulnerable with this scenario and may suffer negative margins if financial risk management tools are not available.

Technological development, as reflected in improved cultivars in this study, was expected to increase crop yields under most situations, especially in the Montérégie region. Technological development contributes to more flexibility and resilience when producers make farm management decisions. This can lead to effective strategies in improving farm operation performance for all sites and scenarios in the short and medium run. Higher land cultivation proportions and labour employment, a reduction in the frequency and magnitude of margin reduction, less participation in crop production safety insurance programs, as well as higher annual net returns either with or without institutional adaptation, were all observed in the analysis with the improved cultivars. In general, it can effectively help producers to reduce production losses and economic vulnerability, and make agricultural production more profitable. However, financial risk management tools are still necessary when facing large margin reduction or when consecutive large losses prevail.

With the subsidy from both federal and provincial governments, producers can benefit from the insurance programs at all sites, conditions and crop varieties. But government payments take place only when real losses occur, especially for AgriStability and ASRA (or RMP). The more these insurance programs payout to producers, the larger the losses producers have suffered. Producers who have registered in both programs can only get the higher payment for the provincial component. As an opposite indicator of farm performance, net benefits from insurance programs were also influenced by climate scenarios and weather conditions. For example, the lowest payouts from the Risk Management Program in North Dundas can be found in the Cold & Humid scenario without water limitation. This indicates that farms in North Dundas would have the best performance under the Cold & Humid scenario when water was not limited. This also corresponds to the projected highest average net return in the same situation. According to the potential income improvement analysis, the net benefit from these insurance programs was subject to decrease in the long run, especially in scenarios and conditions where producers were suffering bad years successively.

An exception exists with the AgriInvest program. Producers in all scenarios can benefit from this risk-free program by making a deposit every year of up to 1.0% of their operation's adjusted net sales (ANS). But there exists a dilemma regarding this program. As institutional insurance is a risk management tool targeting at protecting and benefiting vulnerable producers, it is the producer who has already made substantial net returns, that gains the greatest benefits from this program rather than the vulnerable ones whose adjusted net sales are lower. Thus, it has the potentiality to exacerbate economic inequality in the long run.

6.1. FURTHER RESEARCH

The following suggestions are for further research in the area. First, the current research study had a planning horizon of 30 years from 2010 to 2039. In terms of a planning horizon for climate change, this would be considered a short to medium timeframe. Climate change, however, is a long-term phenomenon and will require long-term adaptation strategies, in particular if climate scenarios become more extreme or if ecological problems are incorporated into the analysis. Thus, a study with a longer timeframe, for example 50 years, would be appropriate.

A second area for future research is with the cost of production and crop price projections. These projections were based on historical monthly data using Monte Carlo simulation methods for each province, which results in the net returns to be not comparable between the sites in the two provinces. These projections were done separately from the crop yield projection based on the assumption that all producers from these representative farms are price takers and have little power to affect regional or national market prices. It would be interesting to compare the net income from the representative farms in both provinces. This would require that the historical data to be comparable, which is difficult with the current cost of production data. In addition, this study did not take into account extreme events when projecting crop prices. In further research, crop prices could be simulated more consistently with yields both locally and internationally. This would allow extreme events, to impact the supply function of the crops and thus crop prices. In order to incorporate this change into the analysis, a model could be constructed that would include all of the important variables that determine supply and demand. This model could include consumer perceptions, changes in dietary preferences, changes in income, precipitations, extreme events in other major agricultural supply areas, pest outbreaks and crop failure. Although the effects of climate change are likely to be slower and more gradual than other events, dramatic changes in market behavior can take place rapidly corresponding to major shifts in perceptions (Just 2001).

Another area for future research would be to investigate in more detail the saving and lending activities. In this study, the only saving activity that was accounted for was the AgriInvest program, but this was still outside the optimization model. However, borrowing and lending activities will certainly play an important role in the decision-making processes and could result in the adoption of different strategies. Thus they need to be explicitly introduced into the optimization modelling process so as to find out whether they would influence the resource allocation, net income, as well as the insurance portfolio, and to what extent.

Finally, additional research could be done on increasing the number of crops in the model. Expanding the number of crops could result in a different resource allocation and thus net income based on comparative advantage, especially if diversification decreases financial or production risks. In addition, livestock and dairy operations can also be considered in the long run since it will have a substantial influence on the demand for feed crops, and thus the field crop land allocation and crop prices.

6.2. POLICY RECOMMENDATIONS

At the institutional level, the main target of adaptation strategies should be to provide a proactive, systematic and integrated way of promoting a stable and resilient framework to protect the vulnerable. Incentives should be provided at this level to increase resilience at the farm level rather than increase the level of uncertainty or unnecessary risks.

In order to deal with future risks of climate change, public infrastructures, such as transportation and communication network, must first be constructed to mitigate the magnitude of potential losses. Government could work with the private sector to provide vulnerable producers with new crop insurance, with emphasis on preventive strategies and regional disasters. In this way, the right incentives should be provided to encourage producers to be self-resilient and preserving financial sustainability. This can work efficiently in helping absorb large production and economic shocks caused by climate change. Institutional strategies have to evolve; however, it also needs to take security of expectations into consideration. Institutional change that is too rapid creates uncertainty and decreases the security of expectations of the producers (Rutherford 1983). Government also needs to partner with scientists in promoting technological development of crop varieties. This study suggests that this is an effective strategy to reduce producers' production and economic vulnerability. Government policies that promote trade or eliminate trade barriers can play a role of securing commodity markets and decrease market risk.

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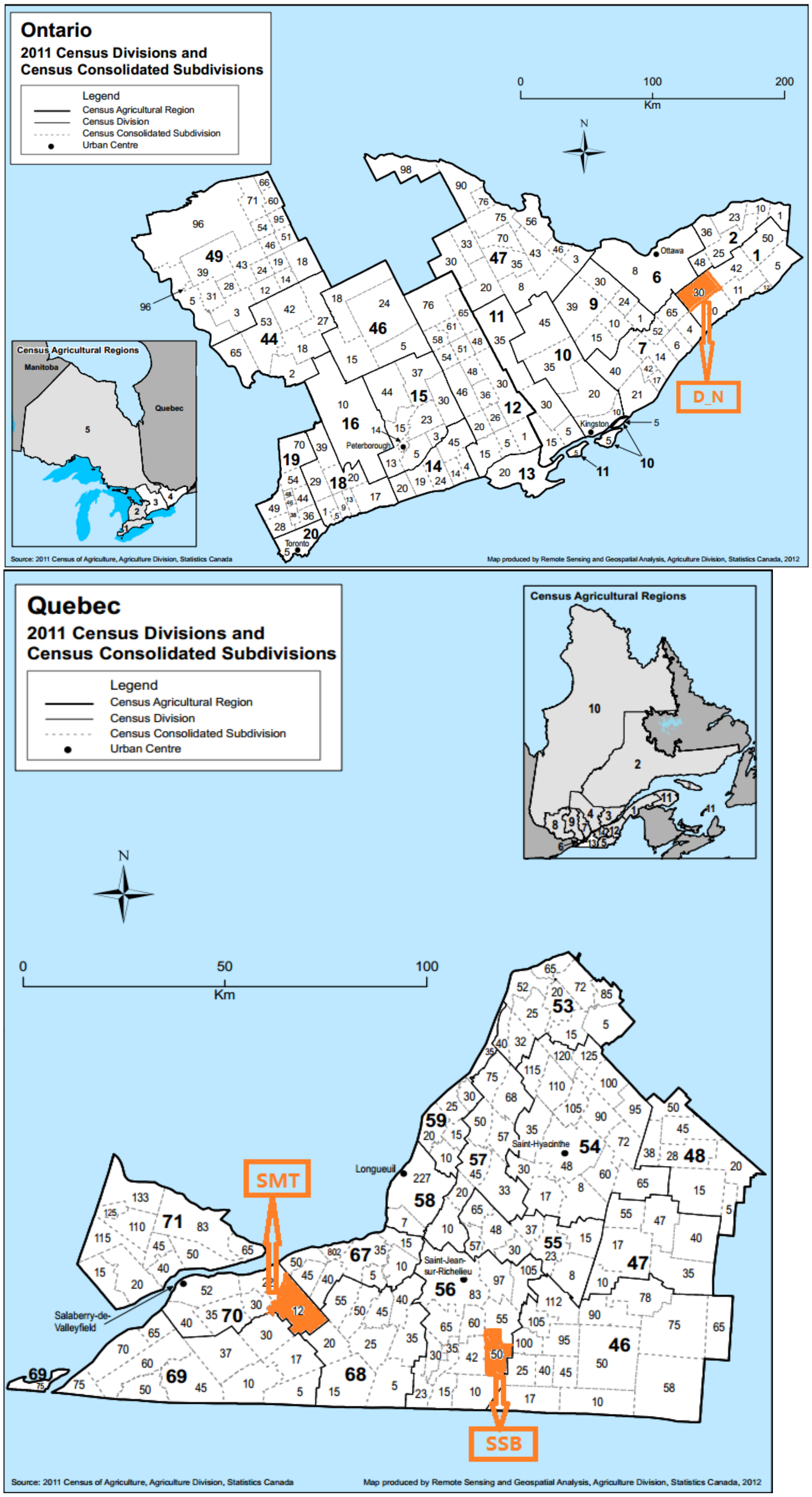
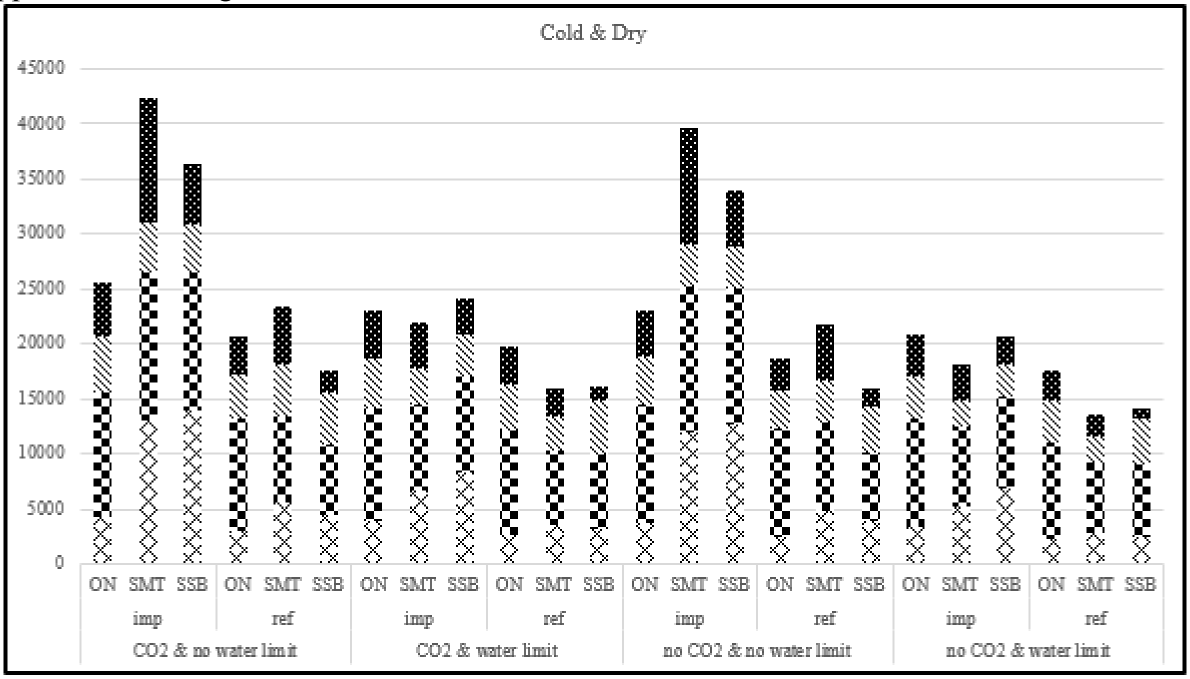
APPENDIX

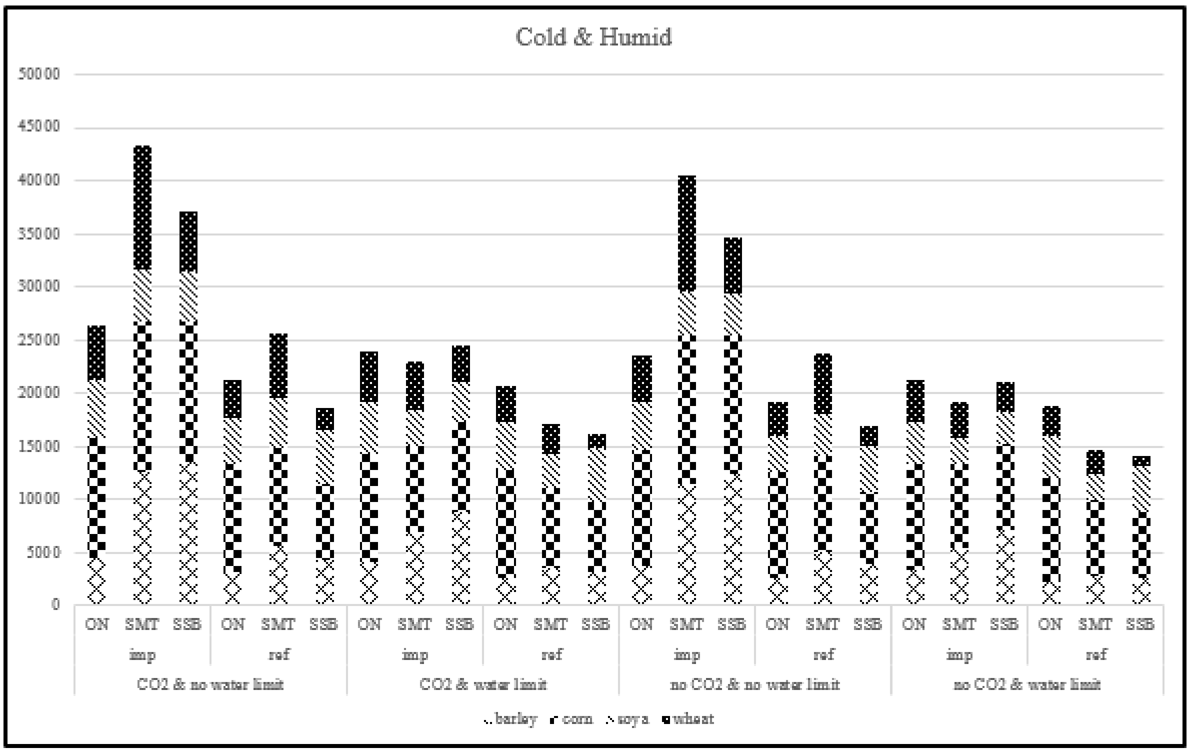
Appendix 1: Relative Location of the Selected Sites in Québec and Ontario



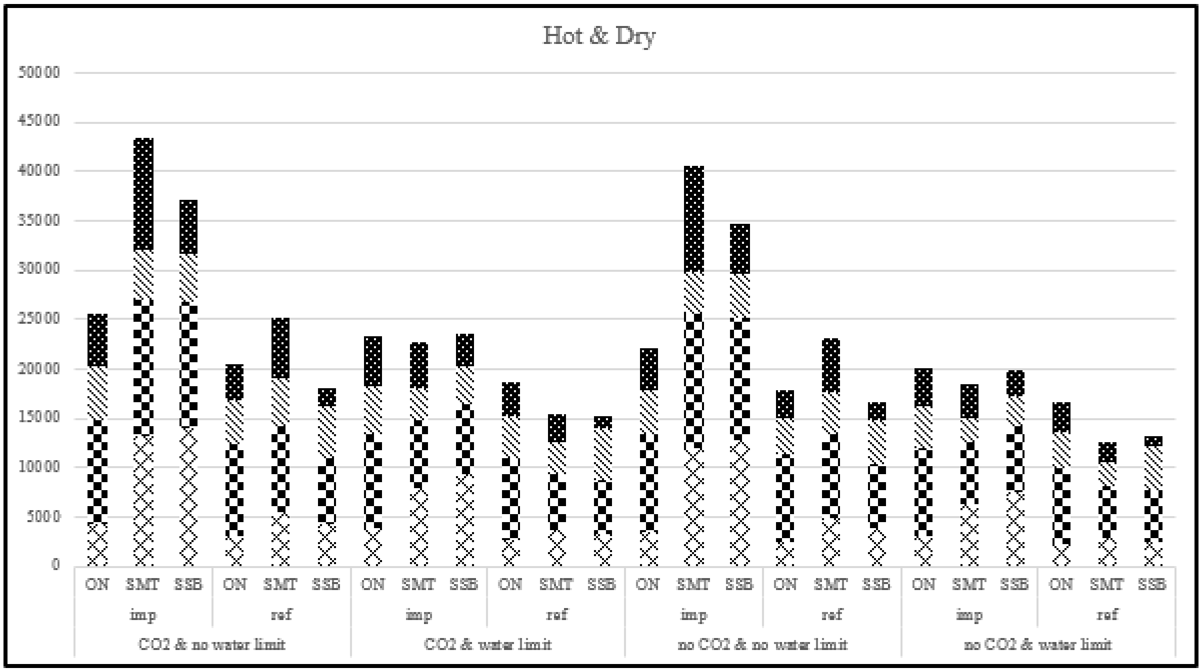
Source: 2011 Census of Agriculture, Agriculture Division, Statistics Canada

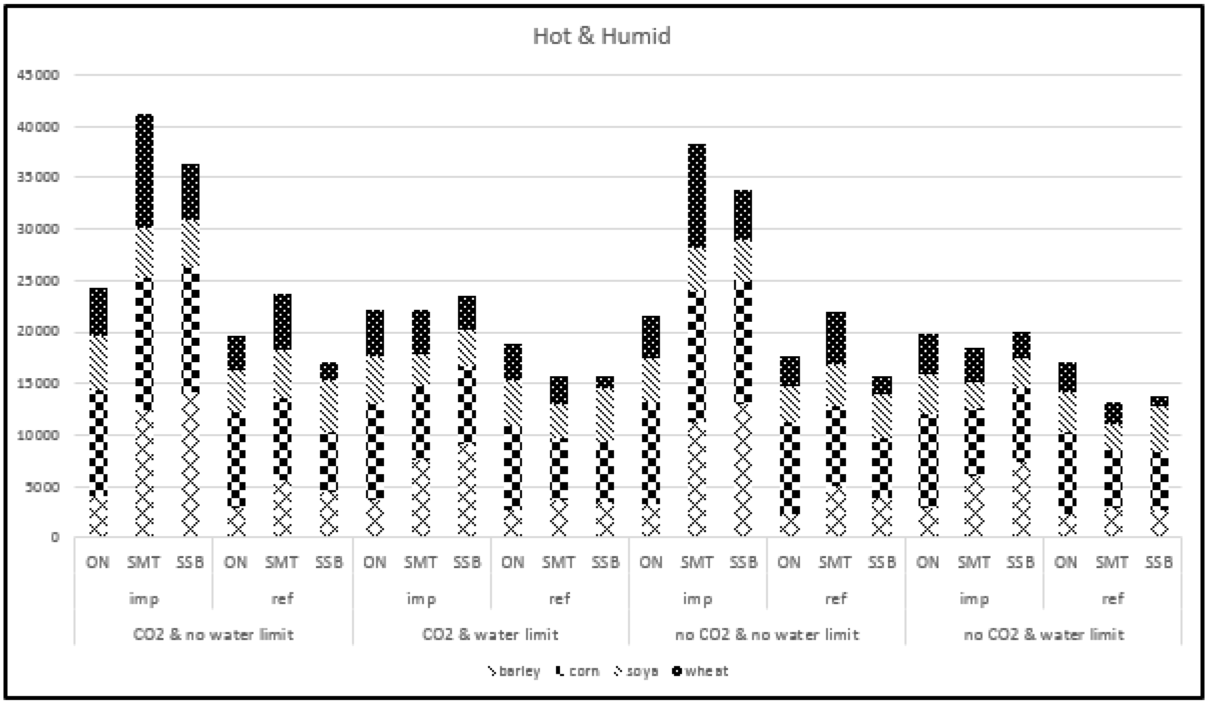
Appendix 2: Average Simulated Yields, 2010-2039



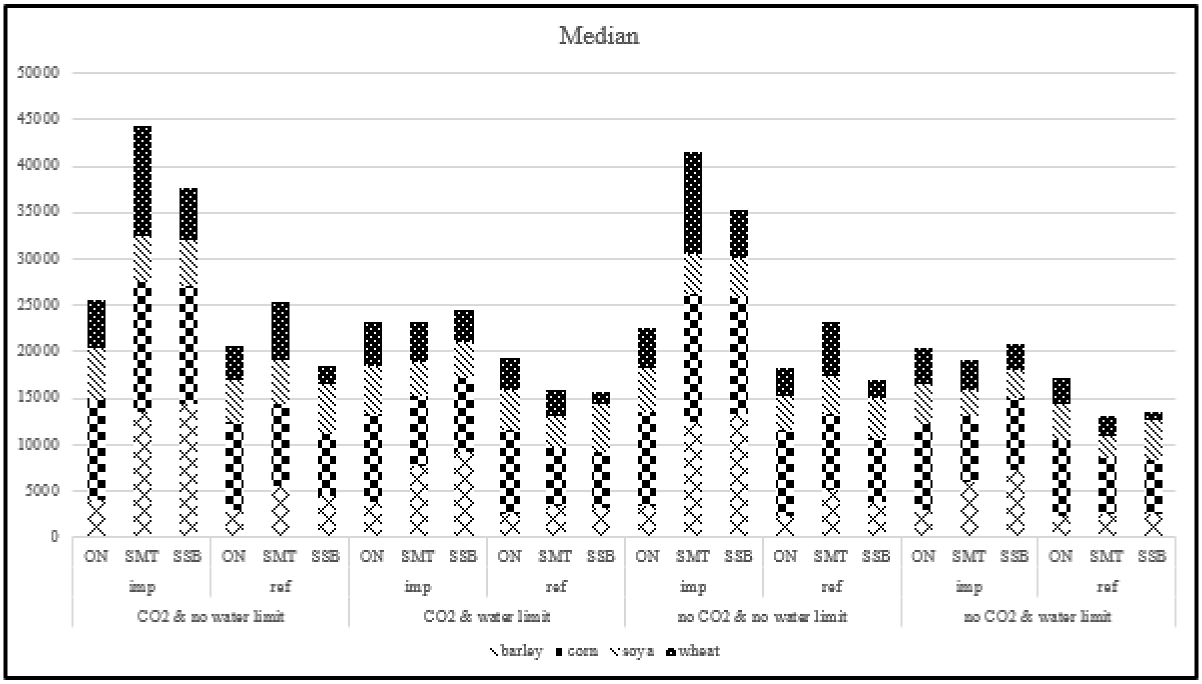


Continued


Hot & Dry
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB
imp ref imp ref imp ref imp ref
CO2 & no water limit
CO2 & water limit
no CO2 & no water limit
no CO2 & water limit

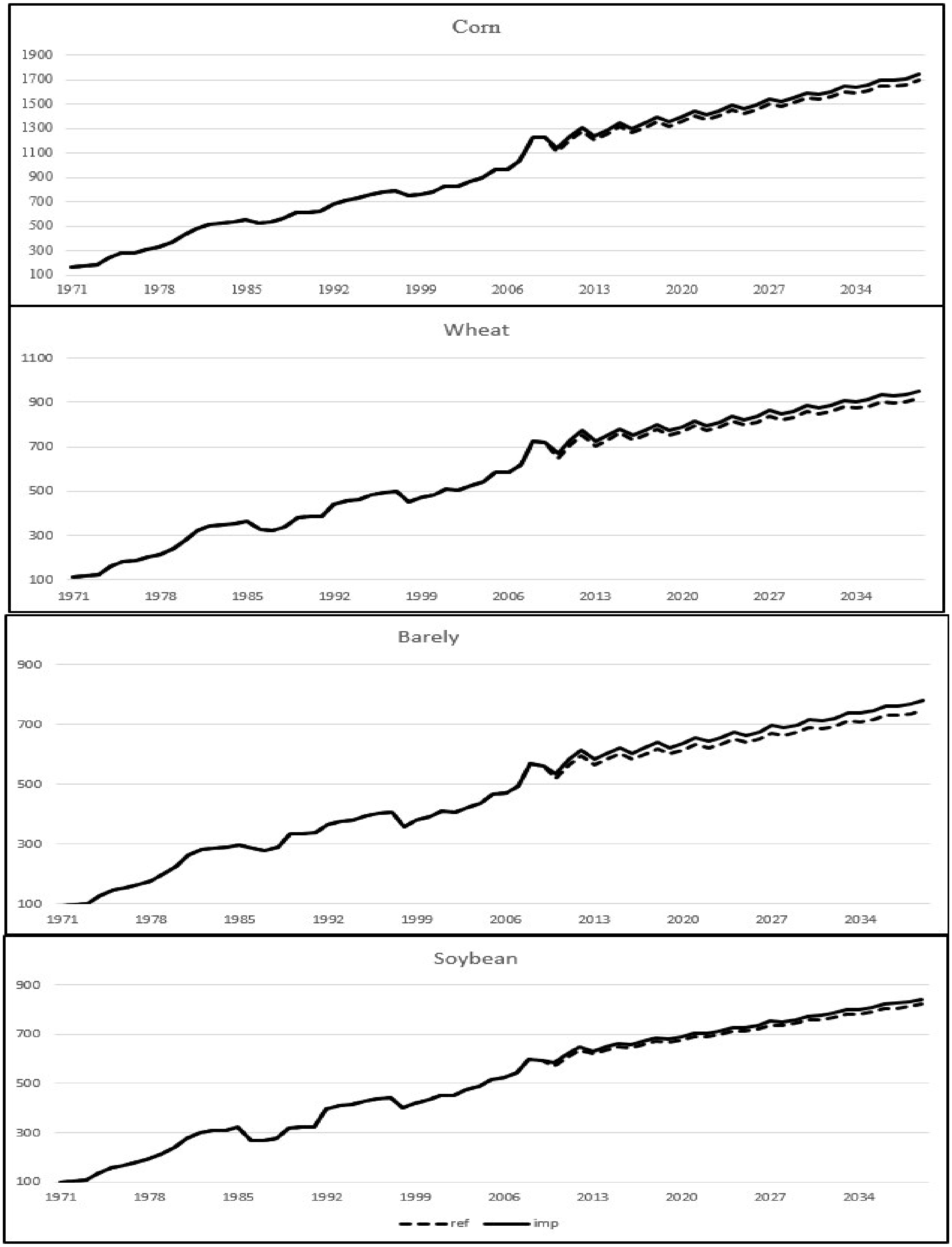

Hot & Humid
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB
imp ref imp ref imp ref imp ref
CO2 & no water limit
CO2 & water limit
no CO2 & no water limit
no CO2 & water limit
barley corn soya wheat

Continued

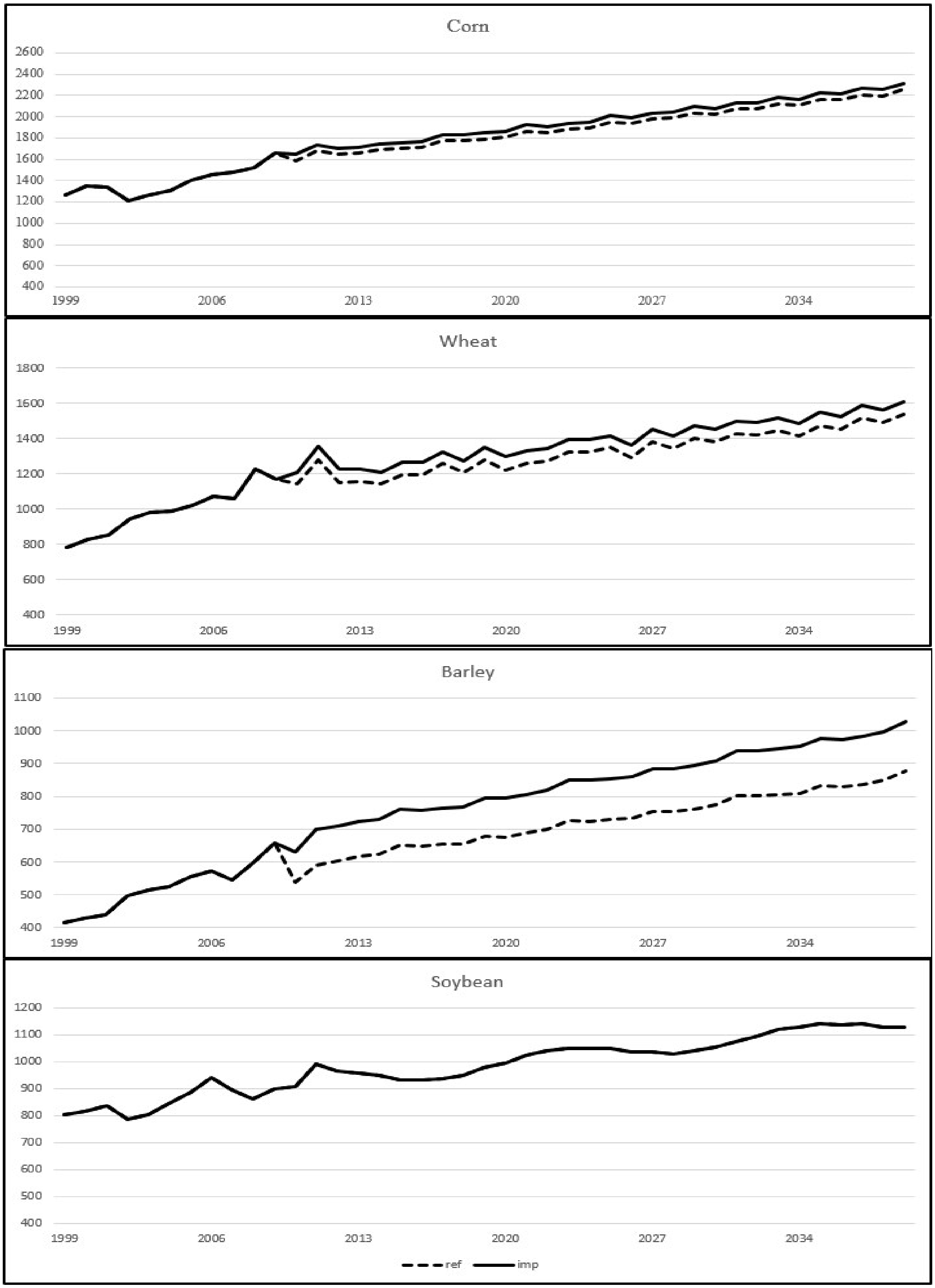

Median
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB ON SMT SSB
imp ref imp ref imp ref imp ref
CO2 & no water limit
CO2 & water limit
no CO2 & no water limit
no CO2 & water limit
barley corn soya wheat

Appendix 3: Historical and Simulated Cost of Production for both Reference and improved cultivar

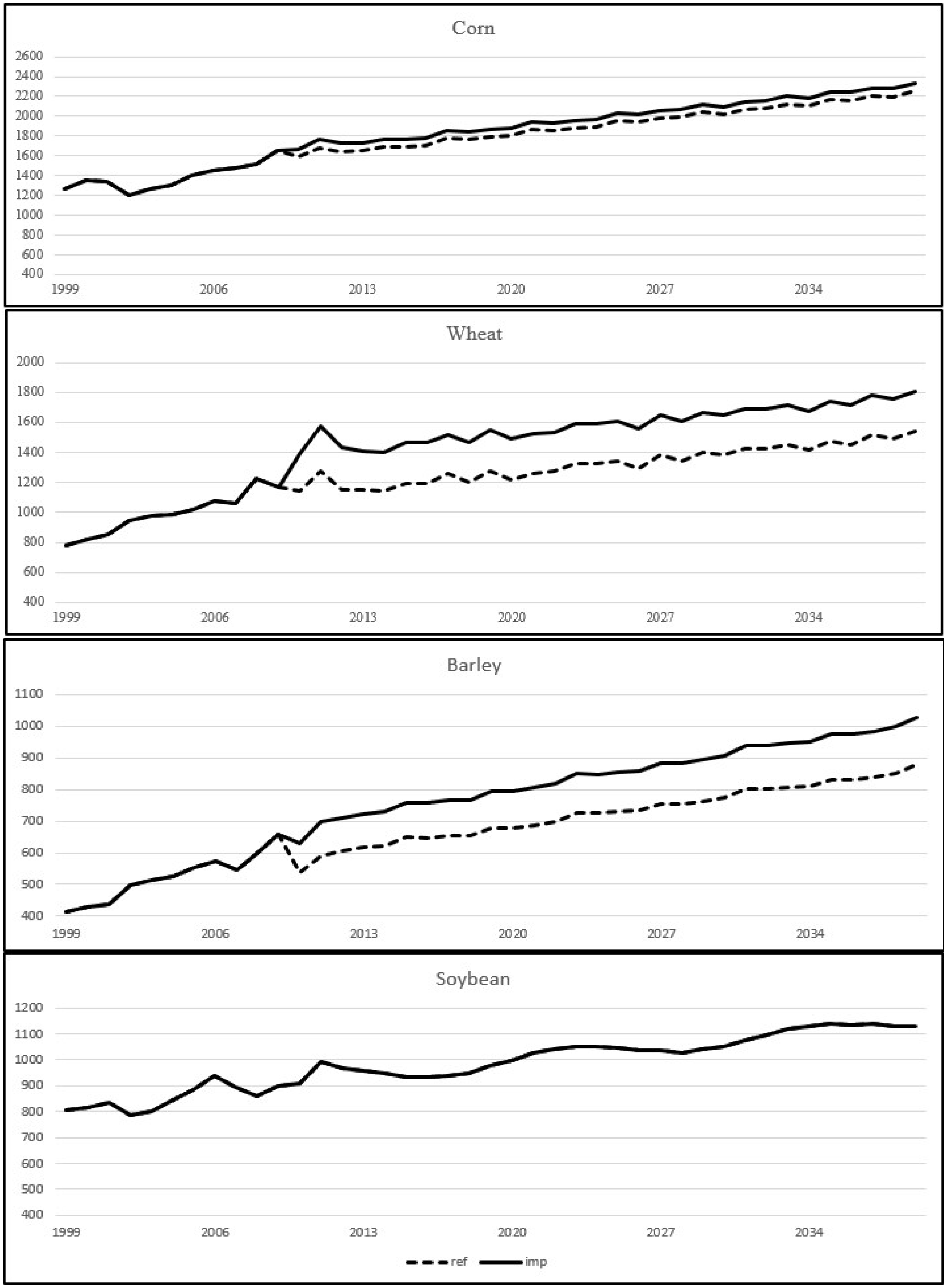
Panel_1: Cost of Production in North Dundas



Panel_2: Cost of Production in Ste-Martine



Panel_3: Cost of Production in St-Sébastien



Appendix 4: Optimal Average Annual Land Allocation

	Site	CO_2 and Water Conditions	Hot & Dry					Hot & Humid					Median					Cold & Dry					Cold & Humid				
			corn	wheat	barley	soya	% of Available Area	corn	wheat	barley	soya	% of Available Area	corn	wheat	barley	soya	% of Available Area	corn	wheat	barley	soya	% of Available Area	corn	wheat	barley	soya	% of Available Area
			(in ha)																								
Ref	SMT	CO2 & No Water Limit	31	8	42	182	75.1	13	6	61	179	74.0	30	10	45	179	75.4	17	5	58	180	74.3	37	7	44	179	76.3
		CO2 & Water Limit	17	4	15	54	25.7	11	3	46	145	58.6	16	2	44	147	59.7	19	2	40	143	58.3	26	3	33	146	59.4
		No CO2 & No Water Limit	34	10	45	178	76.3	12	6	62	177	73.4	36	10	45	176	76.3	20	9	50	176	72.9	47	8	43	174	77.7
		No CO2 & Water Limit	7	2	23	86	33.7	7	2	27	96	37.7	13	2	20	89	35.4	9	2	19	82	32.0	25	2	16	93	38.9
	SSB	CO2 & No Water Limit	19	1	59	181	74.3	15	1	63	180	74.0	22	1	56	181	74.3	15	1	63	180	74.0	24	1	55	181	74.6
		CO2 & Water Limit	23	1	56	181	74.6	22	1	56	181	74.3	30	1	48	182	74.6	32	1	47	182	74.9	30	1	49	182	74.9
		No CO2 & No Water Limit	18	1	60	180	74.0	14	2	63	180	74.0	22	1	56	181	74.3	17	1	59	176	72.3	24	1	54	180	74.0
		No CO2 & Water Limit	22	2	55	180	74.0	23	2	53	179	73.4	32	2	46	181	74.6	35	2	41	178	73.1	33	2	44	180	74.0
	D_N	CO2 & No Water Limit	101	6	0	178	81.4	110	6	0	174	82.9	110	6	0	173	82.6	115	6	0	171	83.4	116	6	0	170	83.4
		CO2 & Water Limit	90	7	0	182	79.7	78	9	0	186	78.0	108	6	0	174	82.3	100	6	0	177	80.9	113	6	0	172	83.1
		No CO2 & No Water Limit	109	5	0	174	82.3	111	6	0	173	82.9	111	5	0	173	82.6	126	4	0	167	84.9	127	6	0	165	85.1
		No CO2 & Water Limit	84	7	0	185	78.9	82	7	0	186	78.6	104	7	0	176	82.0	100	6	0	178	81.1	118	6	0	169	83.7
Imp	SMT	CO2 & No Water Limit	115	53	88	77	95.1	92	55	85	92	92.6	120	59	92	66	96.3	117	51	98	71	96.3	124	56	92	66	96.6
		CO2 & Water Limit	14	8	73	157	72.0	12	6	69	160	70.6	24	6	74	156	74.3	28	5	68	153	72.6	29	5	68	156	73.7
		No CO2 & No Water Limit	119	53	88	74	95.4	115	48	91	79	95.1	129	59	93	60	97.4	133	56	100	54	98.0	135	60	93	55	98.0
		No CO2 & Water Limit	10	6	48	106	48.6	9	4	44	107	46.9	20	4	44	116	52.6	23	4	41	94	46.3	32	4	44	104	52.6
	SSB	CO2 & No Water Limit	93	1	89	126	88.3	73	1	88	136	85.1	107	1	89	119	90.3	96	1	90	123	88.6	116	1	86	117	91.4
		CO2 & Water Limit	18	1	73	172	75.4	14	3	70	175	74.9	23	1	74	169	76.3	25	1	64	175	75.7	23	1	69	172	75.7
		No CO2 & No Water Limit	114	1	94	112	91.7	88	1	89	128	87.4	124	1	95	107	93.4	126	1	96	105	93.7	133	1	91	105	94.3
		No CO2 & Water Limit	18	1	69	175	75.1	17	2	68	176	75.1	36	1	66	168	77.4	34	1	56	175	76.0	33	1	60	173	76.3
	D_N	CO2 & No Water Limit	98	7	1	177	80.9	109	7	0	173	82.6	110	6	0	173	82.6	112	8	0	171	83.1	110	8	2	171	83.1
		CO2 & Water Limit	72	8	5	126	60.3	90	9	0	181	80.0	104	8	1	175	82.3	105	8	1	174	82.3	106	8	2	173	82.6
		No CO2 & No Water Limit	107	6	0	175	82.3	109	7	0	173	82.6	110	6	0	173	82.6	123	6	0	167	84.6	127	8	0	164	85.4
		No CO2 & Water Limit	99	7	0	178	81.1	105	7	0	175	82.0	109	6	0	173	82.3	110	7	0	172	82.6	114	8	0	170	83.4

Appendix 5: Numbers of Years with Margin Reduction under Optimal Decisions

	Site	CO_2 and Water Conditions	Hot & Dry				Hot & Humid				Median				Cold & Dry				Cold & Humid			
			<0	0-30%	30%-100%	>100%	<0	0-30%	30%-100%	>100%	<0	0-30%	30%-100%	>100%	<0	0-30%	30%-100%	>100%	<0	0-30%	30%-100%	>100%
Ref	SMT	CO2 & No Water Limit	15	10	5	0	15	11	4	0	15	9	6	0	17	6	7	0	15	8	7	0
		CO2 & Water Limit	12	5	4	9	14	2	11	3	13	2	12	3	14	3	11	2	15	3	9	3
		No CO2 & No Water Limit	14	9	7	0	15	8	7	0	15	6	9	0	17	6	7	0	14	8	8	0
		No CO2 & Water Limit	12	4	2	12	13	1	3	13	12	3	4	11	12	5	3	10	12	3	4	11
	SSB	CO2 & No Water Limit	16	8	6	0	17	5	8	0	16	7	7	0	17	5	8	0	17	5	8	0
		CO2 & Water Limit	16	5	9	0	17	5	8	0	16	5	9	0	18	3	9	0	16	6	8	0
		No CO2 & No Water Limit	17	5	8	0	16	5	9	0	17	5	8	0	17	4	9	0	18	3	9	0
		No CO2 & Water Limit	15	6	9	0	16	5	9	0	15	5	10	0	17	3	10	0	16	6	8	0
	D_N	CO2 & No Water Limit	17	7	6	0	17	7	6	0	16	8	6	0	16	9	5	0	15	7	8	0
		CO2 & Water Limit	16	6	8	0	18	5	7	0	16	8	6	0	16	6	8	0	15	8	7	0
		No CO2 & No Water Limit	17	6	7	0	17	8	5	0	15	9	6	0	16	7	7	0	15	5	10	0
		No CO2 & Water Limit	16	5	9	0	18	5	7	0	16	8	6	0	16	6	8	0	15	7	8	0
Imp	SMT	CO2 & No Water Limit	14	15	1	0	13	16	1	0	12	17	1	0	12	16	2	0	12	17	1	0
		CO2 & Water Limit	14	1	15	0	13	4	13	0	14	2	14	0	14	5	11	0	15	2	13	0
		No CO2 & No Water Limit	13	16	1	0	12	17	1	0	12	17	1	0	14	12	4	0	13	13	4	0
		No CO2 & Water Limit	14	1	10	5	12	2	8	8	14	1	9	6	12	3	6	9	13	1	9	7
	SSB	CO2 & No Water Limit	16	12	2	0	16	12	2	0	12	17	1	0	12	17	1	0	15	13	2	0
		CO2 & Water Limit	18	8	4	0	17	10	3	0	16	10	4	0	17	9	4	0	17	9	4	0
		No CO2 & No Water Limit	16	12	2	0	16	10	4	0	14	14	2	0	12	15	3	0	15	12	3	0
		No CO2 & Water Limit	18	5	7	0	17	7	6	0	16	7	7	0	17	6	7	0	17	6	7	0
	D_N	CO2 & No Water Limit	17	10	3	0	17	7	6	0	16	10	4	0	16	11	3	0	15	11	4	0
		CO2 & Water Limit	13	5	12	0	16	7	7	0	16	9	5	0	16	9	5	0	15	8	7	0
		No CO2 & No Water Limit	17	8	5	0	17	8	5	0	16	8	6	0	16	10	4	0	15	9	6	0
		No CO2 & Water Limit	17	6	7	0	17	6	7	0	16	8	6	0	16	9	5	0	15	7	8	0