

**Climate Change Impacts and Adaptation
A Literature Review of the Canadian Agriculture Sector**

July, 2011

Preface

The following literature review seeks to capture and summarize current research in the field of climate change adaptation in the agriculture sector. While the review is mainly focused on peer reviewed scientific research, there are many examples of adaptation efforts within levels of government. The review was initially focused on adaptation in an Ontario agriculture setting and then expanded into other parts of Canada with some key examples in the United States and Internationally.

1.0 Methods

This literature review examines studies conducted mainly in Ontario, followed by an expansion into Canada, and select literature from United States and international sources. Studies between 2000 and June 2011 were reviewed. Searches were primarily conducted through Google Scholar using a number of key word search strings to retrieve relevant documents.

Examples of key word phrases:

1. Agriculture adaptation Ontario
2. Agriculture adaptation Canada
3. Agriculture adaptation Ontario climate change
4. Adaptation vulnerability Ontario Agriculture
5. Adaptation Climate Change Vulnerability Ontario Agriculture
6. Climate Change Vulnerability Ontario Agriculture
7. Agriculture Risk Ontario Climate Change

In addition to key word search strings, the literature review included author searches as well as reviews of governmental literature and websites.

2.0 Agriculture in Ontario

The agricultural sector contributes to a substantive piece of Ontario's economy. In Ontario, more than 57,000 farms contribute \$10.3 billion to the Provincial GDP and capture close to one quarter of the country's national farm cash receipts. While the sector's importance to both the economy and food supply is apparent, agriculture is quite sensitive to changes in weather and climate. The vulnerability of the agriculture sector to the impacts of climate change depends on the degree to which it is able to cope with current weather and climate conditions as well as its capacity to recognize future threats as climate continues to change.

Current climate models suggest that Ontario could experience average annual temperature increases in the range of 2.5° C to 3.7° C by the 2050s. The spatial variability of these increases will mean more significant challenges on some parts of the province. Given that the European Union considers increases to global average temperatures beyond 2 °C to be 'dangerous', these average annual increases in Ontario, combined with continued climate variability and extreme events, the agriculture sector will be forced to cope beyond the traditional changes noted through time.

In Ontario, climate change will manifest itself in many ways including:

- Changes in precipitation regimes i.e. wetter winters, rainier winters and dryer, hotter summers;
- Changes in drought frequency and severity;
- Changes to the frequency and intensity of storms;
- Increases to average annual and average seasonal air temperatures;
- Warmer winter temperatures, particularly daytime minimum temperatures;
- Changes in soil temperature and moisture.

From these climate and weather changes stem both risks and opportunities for the agricultural sector. Negative impacts include:

- Yield changes for vegetable and grain crops;
- Negative effects on forage crops;
- Increases in pests, diseases, weeds, and fungi;
- Crop damage due to extreme weather events (i.e. heat waves and freezing rain);
- Increases in drought stress and increases in future water demands;
- Increases in evapotranspiration;
- Increases of stress for livestock with extreme weather event (i.e. heat waves).

While not often discussed and properly evaluated, there may be some positive impacts from climate change which could include:

- Potential increases in soil moisture;
- Potential increases to the length of the growing season (i.e. earlier start to planting season);
- Increases to crop production and yields;
- Potential to grow new crop species in a warmer climate;
- Increases in land value.

The impacts of climate change will vary geographically with some regions being warmer or cooler and others wetter or drier. Similar to other sectors, the net impacts of climate change on agriculture are still not fully clear as is the capacity to handle climate change through adaptation. Historically, farmers have been considered highly adaptable to weather variability, but climate change may pose new unpredictable risks for the future. Continued dialogue

between the science community and agriculture stakeholders will ensure that new science provides input for decision making and that climate change is embedded within existing management practices at the local and farm level.

The potential increase of intense weather events should also be of concern to both farmers and all levels of government. Past examples of severe drought in Canada during the 1930s and early 2000 demonstrate farmer's limitations to severe weather events. Farmers will be able to adapt to many of climate change's challenges, but there may be limits to levels of coping for agricultural producers.

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1.1 Adaptation and Agriculture

At current, Ontario farmers are not fully engaged in planning for potential climate change impacts on both an individual or community level. Farmers have stated as being apt and able to cope and adapt to future climate change impacts while seeing the issue as futuristic and long term. Farmers cope with weather patterns on a daily, monthly, seasonal and annual basis and feel confident to be able to adjust to potential risks. Many farmers cite reliance on technology and best management practices to mitigate climate change risks. Some methods currently being applied to reduce climate and weather risks include:

- Crop and pasture rotation;
- Fallowing of fields, and low or no tillage techniques;
- Increase implementation of irrigation, fertilizer, pesticides, or fungicides;
- The use of variety of genetic strains and vigour lines of crops or livestock;
- Physical barriers (i.e. wind breaks, buffer strips);
- Improvement of facilities (i.e. improvement of manure storage facilities);
- Changes in planting or harvesting dates;
- Changes of crops or livestock;
- Diversification of crops and livestock, and income;
- Proper monitoring techniques.

In addition and correctly, many farmers are concerned with immediate, non-weather-related risks, such as total production and yields, market fluctuations, declining farm income, and overall declining interest in farming. These 'market' variables are beyond the control of individual farmers and can present significant challenges to farm viability. Many farmers also do not have the option to adapt immediately to climate change impacts:

About 12 or 13 years ago my brother told me, "I see where they are predicting record drought this year, and record temperatures, and if I was you I wouldn't plant anything. They are calling for a record bad year." And I told him, "I got land rented, I got land bought, I got tractors bought and leased, I got people working for me, I can't just say I'm not going to farm this year because they are predicting a bad year." (Crane et al, 2001).

It is for these reasons that climate change adaptation is not strongly viewed as a short term priority for the sector in comparison to other equally important challenges. In order to raise awareness of the need for adaptive management, education material and programs would help farmers become better informed of the potential impacts from climate change (i.e. increase in

severe storms) so that they may best prepare for future climate change scenarios. Researchers and educators must also carry a responsibility to better inform farmers of the potential risks and opportunities.

Education on a local level requires the support of all levels of government. Currently, agricultural adaptation guides are in the infancy stages and few municipalities have begun to implement climate adaptation strategies. Research is currently being conducted in select rural agricultural communities in Ontario. These case studies outline the barriers and advantages towards climate adaptation. Communities are not yet at the adaptation implementation stage. Adaptation on a farm level is occurring mostly due to non-climate conditions (economic, political, etc) pressures.

In a report released in 2010, Ontario's Expert Panel on Climate Change Adaptation developed a series of 59 recommendations that would see adaptation measures implemented throughout various government departments, including recommendations geared toward the agricultural sector. The Government of Canada is addressing climate change and adaptation by outlining climate change mitigation and adaptation strategies over the next 3 – 5 years, which will result in direct and indirect impacts upon agriculture sector. While few communities across Canada have begun to strategize for future climate change impacts, six communities are leading the way with specific adaptation pilot projects. Internationally, examples of policies and strategies include the National Adaptation Strategy developed by eight EU Member States, outline agriculture adaptation policies and framework for a broad region.

There is no single approach to climate change adaptation. Communities and municipalities each have to contend with unique geography, topography, and climatic conditions, and socioeconomic conditions therefore making climate change adaptation unique to each community. Governments traditionally have placed more emphasis on GHG mitigation to deal with climate change. That focus has now shifted to include recognition of risks from the impacts of climate change; impacts that are occurring now and will continue into the future.

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1.2 Barriers

Adapting to changed climate often encounters barriers at the farm and/or local level. Some of these barriers include:

1. Lack of understanding the state of the science and research in the field: there still is an air of uncertainty and imperfection around climate change therefore it is difficult for farmers to weigh out the benefits and costs of investing in adaptation.

2. Uneven adaptation: adaptation will be difficult to implement if benefits, such as financial support, infrastructure, and technology and supplies, are unevenly distributed or available to farmers.
3. Financial constraints: adaptation can prove costly. Farmers in a lower income bracket will have less financial opportunity to adapt as cost is a significant factor.
4. Attitudes towards climate change. Many still believe it is a long term future problem, not needing to be currently addressed.
5. Lack of programs or case studies/pilot projects implementing climate adaptation. Federal, provincial, and municipal governments are still in the infancy of developing guidance material to aid the inclusion of climate change into agricultural practices.
6. Rural communities face stresses other than climate change therefore climate change should not be examined in isolation from these factors.
7. Currently, there is a lack of producer organization involvement, shortage of government information, coordination, and direction in regards to climate change adaptation.

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1.3 Summary

Agriculture is inherently sensitive to the variety of weather and climate factors. Changes to average annual air temperature, precipitation regimes, overall climate variability and extreme weather events will pose significant challenges to the agriculture sector in Ontario. While the benefits of climate change should be assessed and recognized by the sector, current research has identified many potential negative impacts to the entire sector. Adaptive measures can be

implemented by agriculture stakeholders to help lessen the effects of climate change, many of which are currently being executed by farmers with little to no extra cost. Researchers are currently investigating to what level adaptation is no longer a viable option for producers, and impacts from climate change become unbearable and unprofitable for farmers.

While communities and other levels of government work towards developing risk-based assessments of the impacts of climate change and implementing adaptation responses, impacts will be most felt at the local level and thus should be addressed at the local level. Successful adaptation will not only work toward building resiliency in the agriculture sector, but should also attempt to strengthen the capacity required to plan and act on climate variability and change.

2.0 Summary of References

1. Climate change and agriculture in the Mid-Atlantic Region

Abler, D. and Shortle, J. 2000. Climate change and agriculture in the Mid-Atlantic Region. *Climate Research*, Vol. 14: 185 – 194.

Abstract

Previous agricultural risk assessments in relation to climate change of the mid-Atlantic suggest the agricultural sector will be severely affected. This study, however, found that climate change impacts may provide both negative and positive impacts for local communities. Further research is needed to fully understand the environmental impacts on agricultural due to the changing climate.

2. AAFC's Climate Change Strategy: A Path Forward for Canadian Agriculture

Agriculture and Agri-Food Canada. 2010. AAFC's Climate Change Strategy: A Path Forward for Canadian Agriculture. Agriculture and Agri-Food Canada.

Abstract

This document addresses the complexities of climate change, the Government of Canada's commitment to addressing climate change, and recommendations to how AAFC can tackle the issue of climate change. Climate change will have both negative and positive consequences within the agricultural sector. Four strategic outcomes will guide climate change mitigation and

adaptation strategies over the next 3 -5 years, and then will be revisited: 1) Greenhouse Gas Emissions Reduced while Sector Productivity is Maintained or Increased 2) Sector Ready to Adapt to Changes in Climate 3) Economic Opportunities Seized and 4) A Global Citizen: Canadian Agricultural Interests Represented Internationally, Information and Knowledge Exchanged with Other Nations and Expertise Shared with Developing Countries.

3. Performance of Agricultural Systems under Contrasting Growing Season Conditions in South-western Quebec.

Almaraz, J.J., Mabood, F., Zhou, X., Strachan, I., Ma, B., and Smith, D.L. 2009. Performance of Agricultural Systems under Contrasting Growing Season Conditions in South-western Quebec. *Journal of Agronomy and Crop Science* 195 (5): 319 – 327.

Abstract

Climate change will alter temperature and precipitation patterns globally, therefore affecting agricultural regions. Crop production systems must adapt to the altered conditions. In South-western Québec, various crops were studied under two tillage and three nitrogen fertility regimes to study their growth over three growing seasons. Two of the seasons were unusually warm and dry and demonstrated that switchgrass and sorghum-sudangrass could be a crop option for south-western Québec with increases in hot and dry seasons in the future. Crops that are naturally adapted to high temperatures and dry conditions (corn) may increase in yield while crops dependent upon wetter conditions (barley) may decrease in production.

4. Multiple exposures and dynamic vulnerability: Evidence from the grape industry in the Okanagan Valley, Canada

Belliveau, S., Smit, B., and Bradshaw, B. 2006. Multiple exposures and dynamic vulnerability: Evidence from the grape industry in the Okanagan Valley, Canada. *Global Environmental Change*, Vol. 16 (4): 364 – 378.

Abstract

This paper assesses the vulnerability of grape growers and winery operators in the Okanagan Valley, B.C due to the risk of climate variability and identifies sources of risk. Through a series of interviews, producers outlined non-climatic risks and climatic and strategies to assist. Adaptation is reliant upon multiple factors, such as government programs, availability to resources and technology, and availability to water.

5. Farm-Level Adaptation to Multiple Risks: Climate Change and other Concerns

Belliveau, S., Bradshaw, B., Smit, B., Reid, S., Ramsey, D., Tarleton, M., and Sawyer, D. 2006. Farm-Level Adaptation to Multiple Risks: Climate Change and other Concerns. University of Guelph.

Abstract

Agriculture is inherently dependent upon climatic conditions, therefore, is a sector frequently cited as being potentially vulnerable to climate change. This report focused upon farm-level adaptation to multiple risks (i.e. climate and non-climate) and areas of vulnerability. Various divisions within the agriculture sector, such as specific crops and livestock, along with specific case studies, were cited. Overall, researchers found that farmers may face greater climatic risks in the future than currently anticipated due to sensitivity to extreme events in both magnitude and frequency. Adaptation efforts mainly rely upon inexpensive irrigation methods and subsidized crop insurance, which will likely be less available in the future. Climate change is viewed as a futuristic issue leading to long term temperature increases and not a current leading concern.

6. Assessing On-Farm Water Use Efficiency in Southern Ontario.

Bernier, M.H. 2008. Assessing On-Farm Water Use Efficiency in Southern Ontario. McGill University, Québec.

Abstract

Southern Ontario's agriculture is highly reliant upon successful irrigation for valuable horticultural crops to overcome weather instability (i.e. insufficient rainfall). With increasing water demands from the agricultural sector, increasing urban development and tourism, and potential climate change impacts, proper irrigation has become an important key factor for water conservation measures. This study found that through five out of six experimental zones, water was either excessively or insufficiently applied. Through the use of proper monitoring technologies, growers can adapt to save and reduce water consumption therefore reducing uncertainty towards irrigation measures.

7. The responses of agriculture in Europe to climate change.

Bindi, R. and Olesen, J. 2011. The responses of agriculture in Europe to climate change. Reg Environ Change 11 (1): 151–158.

Abstract

Climate change is expected to lead to temperature changes that will impact northern Europe during winter months and southern Europe during summer, leading to changes (and losses) in

water availability in the Mediterranean and in the south-west Balkans. Agriculture is expected to be affected both positively and negatively depending on the crop and the adaptation measures taken. Adaptation measures such as changing species, sowing dates, fertilization methods, etc, are options that farmers have either began to adopt or have the potential to adopt in the future.

8. Review of key national and regional policies and incentives to support adaptation and adaptive capacity in the agricultural sector.

Bizikova, L. and Crawford Boettcher, E. 2010. Review of key national and regional policies and incentives to support adaptation and adaptive capacity in the agricultural sector. International Institute for Sustainable Development. Winnipeg, Manitoba.

Abstract

Four *Organization for Economic Co-operation and Development* (OECD) countries plus the European Union (EU) were analyzed to evaluate the risk and vulnerability challenges, the resilience of agricultural sector to how it responds to an array of challenges, including climate change, as well as the types of policies and measures that are being considered to support adaption measures. General policy directions included: reducing sensitivity, increasing adaptive capacity, addressing specific risks related to climate change and variability, furthering sector-specific opportunities in the context of a changing climate, and supporting communication and research efforts. Eight EU Member States have adopted their own National Adaptation Strategy (NAS), which incorporates agriculture adaption policies priorities and framework.

9. Canadian communities' guidebook for adaptation to climate change. Including an approach to generate mitigation co-benefits in the context of sustainable development.

Bizikova L., T. Neale and I. Burton 2008. Canadian communities' guidebook for adaptation to climate change. Including an approach to generate mitigation co-benefits in the context of sustainable development. First Edition. Environment Canada and University of British Columbia, Vancouver.

Abstract

Guidelines for helping to build resiliency within a community and to outline long-term priorities are provided in this report. These specific steps could be of use for many communities looking to implement adaptation into municipal policies or beginning to create a dialogue. As well, observed climate trends since 1900 and climate projections 2100 are outlined i.e. Drought: Increased evapotranspiration and widespread drying trend in soil moisture over North America

since the middle of 1950s, and soil moisture is expected to decrease by 2100. Specific case studies are also provided in the document.

10. Drought Research in Canada: A Review, Atmosphere-Ocean, iFirst article: 1–17

Bonsal, Barrie R., Wheaton, Elaine E. , Chipanshi, Aston C. , Lin, Charles , Sauchyn, David J. and Wen, Lei. 2011. Drought Research in Canada: A Review, Atmosphere-Ocean, iFirst article: 1–17

Abstract

Drought poses a serious threat to society and the environment. Canada’s Prairie region has experienced significant drought in the past due to high precipitation variability over time and space. Climate change has the potential to cause significant droughts in the future, and while past and current drought adaptation strategies are being employed, the paper concludes major research gaps and programs needed to aid our ability to understand and predict droughts, model their impacts, and adapt to their effects.

11. Farm-level Adaptation to Climatic Variability and Change: Crop Diversification in the Canadian Prairies.

Bradshaw, B., Dolan, H., and Smit, B. 2004. Farm-level Adaptation to Climatic Variability and Change: Crop Diversification in the Canadian Prairies. Climatic Change 67: 119–141.

Abstract

This document outlines firstly the crop diversification efforts in the Canadian prairies from 1994 – 2002, listing the limitations and strengths for managing risks. Secondly, climate change adaptation is not well understood and this report attempts to outline the current understanding of adaptation methods and techniques.

12. Impacts of Climatic Change on Canadian Agriculture: An Evaluation of Impact Assessment Procedures

Brklacich, M. and Curran, P. 2002. Impacts of Climatic Change on Canadian Agriculture: An Evaluation of Impact Assessment Procedures. Department of Geography and Environmental Studies, Carleton University, Ottawa.

Abstract

This study examines whether the choice of models and model methodology affects the results of agricultural impact assessments. Through various statistical tests it concluded land suitability,

choice of downscaling, and crop yield models, do not bias the results of agricultural impact assessments.

13. Enhancing the Capacity of Canadian Rural Communities to Adapt to Uncertain Future (No. A1397)

Brklacich, M., M. Woodrow, R. McLeman and K. Vodden. 2008. Enhancing the Capacity of Canadian Rural Communities to Adapt to Uncertain Future (No. A1397). Ottawa: Natural Resources Canada Climate Change Impacts and Adaptation Program.

Abstract

The purpose of this study was to identify the barriers to and opportunities for adaptation in three Canadian rural communities. Much adaptation strategies have been at a broadscale (national and/or regional) level and future research should be focused on a community-level research. Research found that rural communities face multiple stressors and that climate change should not be examined in isolation from the other community stressors.

14. Adaptation in Canadian Agriculture to Climatic Variability and Change

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

Abstract

This paper synthesizes research in relation to climate change and agricultural adaptation measures and responses. Many farmers perceived themselves to be well adapted to climate variation due to extensive ‘technological’ resources. As well, many expressed little concern over the issue of climate change itself, such as several types of risks which include production risk, yield risk, price or market risk, institutional risk, financial risk and human (or personal) risk, are higher priority. Intuitional and political factors have tended to diminish the farm level short term risks, but may well increase vulnerability over the long term. Overall, the Canadian agriculture sector remains vulnerable to climate change and its variability.

15. Achieving Adequate Adaptation in Agriculture

Burton, I. and Lim, B. 2005. Achieving Adequate Adaption in Agriculture. *Climatic Change*, 70: 191-200.

Abstract

Adaptation will take place at three levels (local, national, and global). Locally, farmers can employ methods such as changes in seasonality of production, while nationally, governments are being encouraged to incorporate climate change considerations into farm management policies as well as national economic development policies. Globally, little attention has been given towards technical adaptation.

16. Identifying Rural Research Priorities through Community Engagement.

Caldwell, W., Ball, J., Chen, Y., Ainley, S., Dixon, J., Flemming, H., and Lockhart, E. 2010.

Identifying Rural Research Priorities through Community Engagement. Online.

http://www.waynecaldwell.ca/Projects/ruralresearch/RRPP-Final_Report_May_2010.pdf

Abstract

Public input was gathered across 23 Ontario rural communities to identify rural priorities and key research areas to create timely solutions and policy options that can fundamentally address key societal issues. Key issues, such as youth retention, skills/training/education/literacy, sustainable economic development, were some of the key issues. Climate change adaptation policies have the potential to play a key role in many of the issues communities were stating are of importance.

17. Degrees of Change: Climate Warming and the Stakes for Canada.

Canada. National Round Table on the Environment and the Economy. (2010). Degrees of Change: Climate Warming and the Stakes for Canada. Ottawa: NRTEE.

Abstract

Degrees of Change illustrates the Government of Canada's adaptation approach. In regards to the agricultural sector, the report states that farmers will realize opportunities from increased heat, which will lead to adaptation methods through new varieties and new crops, specifically of higher-value. Producers in most regions have strong adaptive capacities due to tradition addressing drought and climate variability through short-term coping strategies.

18. Ontario. In From Impacts to Adaptation: Canada in a Changing Climate 2007

Chiotti, Q., and B. Lavender. 2008. Ontario. In From Impacts to Adaptation: Canada in a Changing Climate 2007. D. S. Lemmen, F. J. Warren, J. Lacroix and E. Bush, eds., 227-274. Ottawa, Government of Canada.

Abstract

Ontario's population is socially, economically, and culturally influenced by climate. Ontario's annual temperatures have increased by as much as 1.4 °C since 1948 and documented water shortages, stressed ecosystems, and disruption to physical infrastructure and water quality, have been occurring. However, Ontario has a strong capacity to adapt to climate change but it is not uniform across subregions and sectors.

19. Adaptation to Climate Change and Climate Variability: The Importance of Understanding Agriculture as Performance.

Crane, T., Roncoli, C., and Hoogenboom. 2001. Adaptation to Climate Change and Climate Variability: The Importance of Understanding Agriculture as Performance. *NJAS -Wageningen Journal of Life Sciences* 57: 179–185.

Abstract

This paper explores adaptive climate cases from the southern United States and Mali. Uncertainty and variability from environmental conditions have led to risk mitigation strategies including diversification of field locations, crops, use of crop insurance, and other activities, assisting in buffering against ecological and economic shocks. Both countries employ adaptation strategies differently, and both appear (currently) unlikely adequate to meet the challenges posed by uncertainties, specifically climate change.

20. North America. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running and M.J. Scott. 2007. North America. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 617-652.

Abstract

This paper explores the potential broad impacts of climate change and adaptation measures to be implemented in various North America sectors. North American agriculture has been exposed historically to many weather events. Climate change however, comes with variable and unpredictable weather, leading to increased vulnerability in the sector. While there have been attempts to model the dynamics of adaptation to climate change, understanding the sectors capacity to cope with climate change remains currently limited. Various adaptation practices, options, and constraints are stated.

21. Status of Climate Change Adaptation in Canada's Agricultural Sector

Government of Canada. 2010. Status of Climate Change Adaptation in Canada's Agricultural Sector. PRI Project Sustainable Development. Online: www.pri-prp.gc.ca

Abstract

This study provided a high level scan of the various provincial and territorial programs available to help the agricultural sector adapt to climate change. In Ontario, the province's response to climate change is coordinated by the Ministry of the Environment and created the Expert Panel on Adaption to provide recommendations. Ontario's Action Plan on Climate Change is responsible for mitigation measures in the agricultural sector. Adaptation is still not a primary focus in programs provided by OMAFRA (Ontario Ministry of Agriculture, Food, and Rural Affairs).

22. Adapting agriculture to climate change

Howden, S.M, Soussana, J.F., Tubiello., F.N., Chhetri, N., Dunlop, M., and Meinke, H. 2007. Adapting agriculture to climate change. The National Academy of Sciences of the USA 104 (50): 19691 – 19696.

Abstract

There is much potential for adaptation in existing agricultural systems, with beneficial results under moderate climate change conditions for cropping systems. However, under more severe climate change conditions limitations of their effectiveness may result. Therefore, more systemic changes in resource allocation must be considered, as well as an integration of climate risk into risk management frameworks, the continued evolution of adaptation science, as well as enhancing communication and management tools developed with decision makers. Few studies exist that assess both the likely effectiveness and adoption rates as response strategies.

23. Looking into the future of agriculture in a changing climate

Iglesias, A., Quiroga, S., and Diz, A. 2011. Looking into the future of agriculture in a changing climate. European Review of Agricultural Economics 3(37): 1 – 21.

Abstract

This report seeks to answer questions such as "how can agriculture deal with an uncertain future?" and, "How do local vulnerabilities and global disparities respond to this uncertain future?". Regionally, Africa and South East Asia appear to be very vulnerable and at high risk to

very high risk to climate change impacts upon agriculture. Climate change will potentially threaten productivity and water resources. Adaptation will pose difficult in these regions.

24. Status of Climate Change Adaptation in Canada's Agricultural Sector

Jacques, L.S., De Vit, C., and Gagnon-Lebrun, F. 2010. Status of Climate Change Adaptation in Canada's Agricultural Sector. Government of Canada, Policy Research Initiative.

Abstract

This study attempted to capture a snapshot of the provincial and territorial programs that can help the agricultural sector adapt to climate change impacts. Overall 1) western provinces are beginning to integrate climate adaptation into government initiative 2) Ontario, Quebec, and the Atlantic Provinces are mobilizing resources and actors within specific organizations and 3) territorial governments are focusing adaptation measures towards food security. It appears climate change adaptation opportunities are only being seized by very few provinces and territories. Most governments have primarily focused upon mitigation strategies and are gradually shifting towards adaptation.

25. Climate Change, Prairie Agriculture, and Prairie Economy: The New Normal

Kulshreshtha, S. 2011. Climate Change, Prairie Agriculture, and Prairie Economy: The New Normal. Canadian Journal of Agricultural Economics 59: 19–44.

Abstract

Climate change is expected to have both positive and negative impacts upon the agricultural sector. The net impacts on agriculture are still not clear as is the various aspects of adaptation implementation. Overall, farmers are considered highly adaptable to weather variability, but climate change may pose a new risk. The creation of a dialogue between scientists and stakeholders need to be an important priority for future projects.

26. Climate impacts and adaption option in agriculture: what we know and what we don't know.

Lotze-Campen, H., and Schellnhuber, H.J. 2009. Climate impacts and adaption option in agriculture: what we know and what we don't know. J. Verbr. Lebensm. 4: 145 – 150.

Abstract

Plant yields and growth will positively and negatively be affected by climate change, which will result from increasing CO2 concentrations, rising temperatures, and changing precipitation patterns and weather events. Climate change may lead to the result of uneven food distribution and threatened security globally, and also result in range in adaptive capacity between

countries. So called developed countries will lead the way towards improving adaptation measures.

27. Impacts of population change on vulnerability and the capacity to adapt to climate change and variability: a typology based on lessons from “a hard country”

McLeman, R. 2010. Impacts of population change on vulnerability and the capacity to adapt to climate change and variability: a typology based on lessons from a hard country. *Population and Environment* DOI: 10.1007/s11111-009-0087-z.

Abstract

This article outlines impacts faced by rural communities vulnerable to climate change and weather variability through analyzing population and demographic change. It reviews the existing literature on the effects of population change on anthropogenic greenhouse gas emissions, on the capacity to adapt to climate change, and the exposure of settlements to risks from climate change. It also provides a case study detailing the relationship between population change and adaptive capacity in a rural eastern Ontario community. Changing demographics and climate patterns place increased stress on local social network.

28. Drought adaptation in rural eastern Oklahoma in the 1930s: lessons for climate change adaptation research.

McLeman, R., Mayo, D, Strebeck, E., and Smit, B. 2008. Drought adaptation in rural eastern Oklahoma in the 1930s: lessons for climate change adaptation research. *Mitig Adapt Strat Glob Change* 13:379 – 400.

Abstract

In the mid-1930s resulted in the mid-USA experiencing an unusually harsh mixture of droughts and extreme rainfall events, leading to large crop failure over successive years. Agriculture adaptation were not adequate for dealing with the scope of the issue, and findings in this report identify the successes and opportunities missed public policy makers, and suggest possible adaptation opportunities for dealing with future climate impacts.

29. Drought and institutional adaptation in the Great Plains of Alberta and Saskatchewan, 1914-1939.

Marchildon, G., Kulshreshtha, S., Wheaton, E., and Sauchyn, D. 2008. Drought and institutional adaptation in the Great Plains of Alberta and Saskatchewan, 1914-1939. *Natural Hazards*, 45: 391 – 411.

Abstract

With successive years of drought, government relief proved too expensive therefore relocation of farmers was encouraged. Through government policies and programs involving water conservation, dam building, and grass replanting, agricultural land was reclaimed. The droughts of 2001-2002 and 1988 would likely have been much worse without the lessons learnt from this specific drought period, making past adaptation options worth revisiting.

30. Impact and adaptation opportunities for European agriculture in response to climatic change and variability.

Mariondo, M., Bindi, M, Kundzewicz, Z., Szwed, M., Chorynski, A., Matczak, P., Radziejewski, M., and Wreford, A. 2010. Impact and adaptation opportunities for European agriculture in response to climatic change and variability. *Mitig Adapt Strategy Glob Change* 15:657–679.

Abstract

General Circulation Models (GCM) were downscaled to simulate potential impacts of a changing climate on the agriculture sector in Europe. A 2+°C scenario lead to higher impacts on crops cultivated in the Mediterranean basin than those contrast to crops cultivated in Northern Europe. Simple no-cost adaptation options (i.e. advancement of sowing dates) are suggested to be used. The costs associated with the creation of adaptation strategies are variable and still unclear. Impact assessments were able to identify specific area and ways that climate change may be exploited and how the negative impacts may be reduced.

31. Hydrologic response to scenarios of climate change in sub watersheds of the Okanagan basin, British Columbia

Merritt, W., Alilia, Y., Barton, M., Taylor, B., Cohen, S., and Neilsen, D. 2006. Hydrologic response to scenarios of climate change in sub watersheds of the Okanagan basin, British Columbia. *Journal of Hydrology* 326 (1-4), 79-108.

Abstract

Using global climate models (GCMs), scenarios of climate change for the Okanagan Basin were generated over three future time periods. All models demonstrated an increase winter temperature and precipitation. All scenarios raised the issue of future water availability in the Basin coinciding with an increased demand from agricultural and domestic water use.

32. Lake Simcoe Protection Plan

Ministry of the Environment, Ministry of the Environment, Ministry of Natural Resources, and Lake Simcoe Region Conservation Authority. 2009. Lake Simcoe Protection Plan. Queen's Printer for Ontario, Ontario.

Abstract

The Lake Simcoe Protection Plan outlines key priorities towards protecting and restoring the ecological health of the Lake Simcoe watershed. In regards to agriculture, farmers in the Lake Simcoe watershed have made significant progress towards assisting in protecting the watershed through improved agricultural practices and technologies, i.e. the instillation of buffer strips and improvement of manure storage facilities. These have been implemented by individual farmers and also through the formal stewardship programs (Environmental Farm Plan Program). Climate change is acknowledged as a future stress in the region and a priority in the plan.

33. Potential impacts of climate change on water availability for crops in the Okanagan Basin, British Columbia.

Neilsen, D., Smith, A.S., Frank, G., Koch, W., Allia, Y., Merritt, W.S., Taylor, W.G., Barton, M., Hall, J.W., and Cohen, S.J. 2006. Potential impacts of climate change on water availability for crops in the Okanagan Basin, British Columbia. *Canadian Journal of Soil Science*, Vol. 88 (5): 921 – 936.

Abstract

This report evaluated the crop water demand in the Okanagan Basin for determined for 1961 to 1990, 2010 to 2039, 2040 to 2069, and 2070 to 2099 under three global climate models. Depending on the model, overall projected water demands increased 12–20% (2010 to 2039), 24–38% (2040 to 2069) and 40–61% (2070 to 2099). Overall, water infrastructure may be inadequate if adaptation methods (i.e. water management strategies) and new technologies (i.e. water saving equipment) are not implemented,

34. Adapting to climate change in Ontario: Report of the expert panel on climate change adaptation

Pearson, D. and I. Burton. 2009. Adapting to climate change in Ontario: Report of the expert panel on climate change adaptation. Toronto: Government of Ontario, Ministry of the Environment.

Abstract

A total of 59 recommendations were suggested in this report. Adaptation measures throughout various government departments must be taken simultaneously to respond to climate change. Ontario economy, society, and environment have been taken into account thus an integrated approach was needed. The series of impacts, strategic goals, and specific recommendations will assist the Government of Ontario to build a climate resilient province.

35. Vulnerability and Adaption to Climate Risks in Southwestern Ontario Farming Systems.

Reid, S., Belliveau, S., Smit, B., and Caldwell, W. 2007. Vulnerability and Adaption to Climate Risks in Southwestern Ontario Farming Systems. Chapter 13: Farming in a changing climate. UBC Press, Canada.

Abstract

This chapter outlines the potential impacts and opportunities with a warming climate. Farmers interviewed stated specific adaptation methods currently used with present climate conditions and extremes. Climate change itself was not an issue of concern too many interviewed, viewing climate change as a long-term and slow moving threat. Current adaptation methods may be useful in future scenarios but it is uncertain under extreme weather events, to what extent adaptation will reduce vulnerability.

36. Vulnerability and adaptation to climate risks in Ontario agriculture

Reid, S., Smit, B., Caldwell, W., and Belliveau, S. 2007. Vulnerability and adaptation to climate risks in Ontario agriculture. *Mitig Adapt Strat Glob Change* 12:609–637

Abstract

A vulnerability approach was used towards assessing climate change adaptation methods for this report of farms in the Perth County, Ontario region. Farmers were asked to identify climate risks on their farms and their responses and risk associated with weather and climate events. Currently, farmers implement a wide array of anticipatory and reactive management strategies to manage climate risks, but it was also noted climate change was not a current issue of concern for many farmers. This lack of knowledge could harm future and long-term climate change adaptations opportunities.

37. Adapting to Climate Change: An introduction to Canadian Municipalities

Richardson, G. R. A. 2010. Adapting to Climate Change: An Introduction for Canadian Municipalities. Ottawa, Ont.. Natural Resources Canada, 40 p.

Abstract

There is no single approach to climate change adaptation. Communities and municipalities each have to contend with unique geography, topography, and climatic conditions, therefore making climate change adaptation unique to each community. Assessing vulnerability is an integral part of adaptation planning processes and must be completed when planning for climate change adaptation. A total of 6 community case studies were discussed how climate change adaptation is being met.

38. Climate change and winter damage to fruit trees in eastern Canada.

Rochette, P., Bélanger, G., Castonguay, Y., Bootsma, A. and Mongrain, D. 2004. Climate change and winter damage to fruit trees in eastern Canada. *Can. J. Plant Sci.* 84: 1113–1125.

Abstract

Variation in climatic conditions, especially during the cold season, is of serious concern in Eastern Canada for fruit producers. Winter temperatures are predicted by 2050 to increase by 2 to 6°C thus impacting fruit trees. Plants are susceptible to variations in snow depths as well. Adaptation methods included new varieties and species were fruit trees are currently grown further north of eastern Canada.

39. Planning for climate change in Canadian rural and resource-based communities.

Sander-Regier, R., McLeman, R., Brklacich, M., and Woodrow, M. 2009. Planning for climate change in Canadian rural and resource-based communities. *Environments Journal* Volume 37(1): 35 – 57.

Abstract

This article discusses the various factors that influence rural communities to manage, plan, and respond to climate risk and uncertainties. The municipality of Edwardsburgh/Cardinal was used as a case study and found that the success of capacity building depends upon factors such as improved coordination across different levels of government, the provision of locally geared information about climate change and the environment, economic diversification, and changing demographic patterns.

40. Saskatchewan's Natural Capital in a Changing Climate: An Assessment of Impacts and Adaptation.

Sauchyn, D., Barrow, E., Fang, X., Henderson, N., Johnston, M., Pomeroy, J., Thorpe, J., Wheaton, E., and Williams, B. 2009. Saskatchewan's Natural Capital in a Changing Climate: An

Assessment of Impacts and Adaptation. Report to Saskatchewan Ministry of Environment from the Prairie Adaptation Research Collaborative, 162 pp.

Abstract

Impacts from climate change are currently evident in Saskatchewan and will become increasingly significant over time. Agriculture plays a large role in Saskatchewan's economy, as does the importance of the natural ecosystems. This assessment documented the expected impacts of climate change on the province's natural resources and industries plus 2) outline adaptation options for resource management practices, policies, and infrastructure.

41. Adaptation to Climate Change in Agriculture: Evaluation of Options

Smit, B., Dolan, H., Skinner, M., Bradshaw, B., and Bryant C. 2001. Adaptation to Climate Change in Agriculture: Evaluation of Options. Department of Geography, University of Guelph.

Abstract

This report describes a consistent and systematically evaluation adaptation method, Multiple Criteria Evaluation (MCE), which is designed to assess alternatives using more than one criterion. This process disguised the adapter (i.e. one who is adapting) and adaptation beneficiary (i.e. one who is benefitting from the adaptation). This process is often neglected during adaptation assessments, and while possible to apply to evaluations consistently, it may not be a necessary and practical exercise as decisions require continual management decisions in the agriculture sector.

42. Adaptation Options in Agriculture to Climate Change: A Typology

Smit, B. and Skinner, M. 2002. Adaptation Options in Agriculture to Climate Change: A Typology. *Mitigation and Adaptation Strategies for Global Change* 7: 85–114.

Abstract

Drawing from Canadian examples, a typology of adaptation classifying and characterizing agricultural adaptation options was developed. Four main categories were determined through research synthesis: (i) technological developments, (ii) government programs and insurance, (iii) farm production practices, and (iv) farm financial management. Results suggest that current adaptation practices are modifications to current farm practices and climate and non-climate conditions (economic, political, etc) affect public policy decision making processes. For future implementation of adaptation options, further research is needed to align the potential adaptation options and existing government and farm-level decision making processes and framework.

43. Indicators of Adaptive Capacity to Climate Change for Agriculture in the Prairie Region of Canada: Comparison with Field Observations

Swanson, D.A., J.C. Hiley, H.D. Venema and R. Grosshans, 2009. Indicators of Adaptive Capacity to Climate Change for Agriculture in the Prairie Region of Canada: Comparison with Field Observations. Working Paper for the Prairie Climate Resilience Project, Winnipeg: International Institute for Sustainable Development.

Abstract

GIS-based indices mapping adaptive capacity from climate change across the Prairie region of Canada resulted in 1) better understanding the capacity of agriculture producers and agro-ecosystems to adapt to weather-related stresses, 2) assessments of adaptive capacity requires many perspectives and players to be on board and 3) while statistics are useless, ultimately adaptive measures are implemented through policies and the use of on-the-ground research.

44. Farm-Level Adaptation to Multiple Risks: Climate Change and Other Concerns

Tarleton, M., and Ramsey, D. 2008. Farm-Level Adaptation to Multiple Risks: Climate Change and Other Concerns. *Journal of Rural and Community Development* 3 (2); 47 – 63.

Abstract

This paper presents the results from a case study reviewing farm-level adaptation with a political, social, and economic focus, and outlined both risks and opportunities from climate change.

45. Sources of information for farmers' adaptation practices in Canada's Prairie agro-ecosystem

Tarnoczi, T.J. and Berkes, F. 2010. Sources of information for farmers' adaptation practices in Canada's Prairie agro-ecosystem. *Climatic Change* 98:299–305.

Abstract

Information available to help farmers adapt in the Canadian Prairies was examined. Focus lay upon soil and water conservation practices, i.e. wetland preserving and maintaining groundcover, and found that information in relation to soil and water conservation information came from a variety of sources. Sources such as industry, government, producers, conservation organization, social and personal experiences, and media were all sited as information points. When implementing adaptation methods, farmers were more open to new practices when learned firsthand through trial and observation. Currently, there is a lack of producer

organization involvement, shortage of government information, coordination, and direction in regards to climate change adaptation.

46. Living with Climate Change: How Prairie Farmers Deal with Increasing Weather Variability.

Terrence, T. and Pearce, W. 2009. Living with Climate Change: How Prairie Farmers Deal with Increasing Weather Variability. Natural Resource Institute, University of Manitoba, Winnipeg.

Abstract

Agriculture is inherently sensitive to weather variability and may be as a sector extremely vulnerable to climate change impacts; therefore, adaptation is necessary to maintain agricultural production and productivity. Prairie producers are able to increase their resiliency through various options, such as using new technology, new crops, and having the flexibility to adapt to any situations.

47. Adaptive capacity for climate change in Canadian rural communities

Wall, E. and Marzall, K. 2006. Adaptive capacity for climate change in Canadian rural communities. *Local Environment* 11(4): 373-97.

Abstract

To achieve long-term sustainability in rural areas, an assessment of the ability to handle stress from various external and internal factors, must be completed. Current literature evaluates capacity evaluation but is sparse regarding implementation methods. This article provides a community capacity assessment method towards specific Canadian rural communities.

48. Agricultural adaptation to climate change in the news

Wall, E., and Smit, B. 2006. Agricultural adaptation to climate change in the news. *Int. J. Sustainable Development*, Vol. 9 (4): 355 – 370.

Abstract

Canadian policy makers and researchers in the climate change field state the lack of interest towards climate change from farmers, due to a misunderstanding towards climate change science and adaptation methods. Media plays a large role in altering producer's attitudes towards climate change.

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

Wall, E, Smit, B., and Wandel, J. 2004. Canadian Agri-food Sector Adaptation to Risks and Opportunities from Climate Change. Position Paper on Climate Change, Impacts, and Adaptation in Canadian Agriculture. C-CIARN Agriculture, Guelph, Ontario.

Abstract

This paper reviews the current state of climate change risks and opportunities for the Canadian agri-food sector, as well as provides recommendations based on an assessment of the outstanding research gaps and issues in research approach and support as well as government policy. Key recommendations such as providing support in adaptation research, assist farmers in employing the vulnerability approach, and improving existing climate and weather data collection, were highlighted.

50. The 2001 - 2002 Vulnerability and Adaptation in Alberta's Special Areas

Wandel, J., Young, G., and Smit, B. 2009. The 2001 - 2002 Vulnerability and Adaptation in Alberta's Special Areas. *Prairie Forum*. Springer 31 (1): 211 – 234.

Abstract

This paper assesses sensitivities and adaptive strategies employed by stakeholders through the 2001-2002 drought in rural Alberta's Special Area. Stakeholders were not equally affected, and many farmers faced challenges, such as access to proper irrigation and loss of crops. Overall, a production loss of \$3.6 billion was recorded for Alberta and Saskatchewan in 2002. Adaptive capacity relied upon access to resources and capital, and noted non-agricultural income sources (i.e. oil and gas leases) buffering a portion of the financial loss due to the drought.

51. Agricultural Adaptation to Drought in Canada: the Case of 2001 to 2002.

Wheaton, E., Koshida, G., Bonsal, B., Johnston, T., Richards, W., and Wittrock, W. 2007. Agricultural Adaptation to Drought in Canada: the Case of 2001 to 2002. Saskatchewan Research Council.

Abstract

The Agricultural Drought Adaptation (ADA) project was created to assess the severity, area and duration of past droughts across Canada. It also estimates the characteristics of future droughts across Canada.

52. Canadian prairie rural communities: their vulnerabilities and adaptive capacities to drought

Wittrock, V., Kulshreshtha, S., and Wheaton, E. 2010. Canadian prairie rural communities: their vulnerabilities and adaptive capacities to drought. *Mitig Adapt Strateg Glob Change* 16: 267–290.

Abstract

This study examines the social and physical vulnerabilities and adaptation measures utilized in the South Saskatchewan River Basin region due to the 2001 – 2002 drought. Communities with unreliable water technologies and supply were the most vulnerable.

53. Climate Change and Agriculture: Impacts, Adaptation and Mitigation.

Wrefort, A., Moran, D., and Adger, N. 2010. *Climate Change and Agriculture: Impacts, Adaptation and Mitigation*. Organization for Economic Co-operation and Development.

Abstract

The report addresses the economic status of climate change impacts in the agricultural sector, particularly addressing the cost of climate change impacts upon agricultural systems, the adaptation responses, and mitigation cost.

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