Christopher R. Bryant · Mamadou A. Sarr
Kénel Délusca *Editors*

Agricultural Adaptation to Climate Change

Springer

Agricultural Adaptation to Climate Change

Christopher R. Bryant • Mamadou A. Sarr
Kénel Délusca
Editors

Agricultural Adaptation to Climate Change

Springer

Editors
Christopher R. Bryant
University of Montréal
Montréal, QC
Canada

School of Environmental Design
and Rural Planning
University of Guelph
Guelph, ON
Canada

Kénel Délusca
Institut des Technologies et des Études
Avancées d'Haïti (ISTEAH)
Port-au-Prince, Cap-Haïtien
Hinche, Haiti

Mamadou A. Sarr
Université de Montréal (Québec, Canada) and
Centre de Suivi Écologique (Dakar, Senegal)
Dakar, Senegal

ISBN 978-3-319-31390-0 ISBN 978-3-319-31392-4 (eBook)
DOI 10.1007/978-3-319-31392-4

Library of Congress Control Number: 2016943180

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

Contents

List of Figures

List of Tables

Chapter 1
Introduction

Christopher R. Bryant, Kénel Délusca, and Mamadou Adama Sarr

Keywords Agricultural adaptation to climate change • Conceptual framework of agricultural adaptation to climate change

1.1 Introduction and a Conceptual Framework

The decision to prepare this book on Climate Change and Agriculture stems from the colloquium (Number 677: Changements climatiques et agriculture (Climate change and agriculture), organized by C.R. Bryant in the context of the congress of ACFAS in 2012). All of the contributions in the book, except for one, are based on presentations made during this colloquium; an additional invitation to Rodrigue Feumba and his team was made which resulted in Chap. 13.

The preparation of this book has also drawn heavily on the research undertaken by the research teams based at the Université de Montréal (directed by Bhawan Singh and Christopher Bryant since the early 1990s (e.g. Bryant et al. 1997, 2000, 2004, 2007, 2008, 2013; Singh et al. 1997, 1998), and also involving at different times researchers from McGill University (Paul Thomassin) and Carleton University (Ottawa) (Michael Brklacich); some of the graduate students and post-doctoral fellows (K. Délusca, M.A. Sarr and M. Woodrow) who were also involved in some of these research teams have taken a lead role in some of the chapters.

C.R. Bryant (✉)
University of Montréal, Montréal, QC, Canada

School of Environmental Design and Rural Planning, University of Guelph, Guelph, ON, Canada
e-mail: christopher.robin.bryant@gmail.com

K. Délusca
Institut des Technologies et des Études Avancées d'Haïti (ISTEAH), Port-au-Prince, Cap-Haïtien, Hinche, Haiti
e-mail: kenel.delusca@gmail.com

M.A. Sarr
Université de Montréal (Québec, Canada) and Centre de Suivi Écologique (Dakar, Senegal), Dakar, Senegal
e-mail: mamadou_sarr74@hotmail.com; adama.sarr@cse.sn

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_1

While dealing with climate change it is important to understand how this phenomenon affects human activities such as agriculture. However, it is also important to understand how human activities especially agriculture can adapt to changing climate conditions – this is therefore the focus of this book. We first start off by presenting a conceptual framework for thinking about agricultural adaptation to Climate Change and Variability (CCV). It is important to emphasize the significance of the variability of climate conditions and how this variability has changed and might continue to change as climate conditions continue to be altered.

The fundamental concepts identified below for achieving a better understanding of the phenomenon and process related to agricultural adaptation to CCV are: (1) The complex nature of the socio-economic systems of agriculture; (2) The ecosystem characteristics of importance to agriculture; (3) The multiple stressors affecting agriculture; and (4) The types of adaptation. Two other considerations are also identified: the spatial scale at which adaptation is being investigated; and the time frame regarding climate change versus the time frame for farmers having to make multiple decisions. All of these components have been suggested based on the research and reflections upon which this book has been based as well as other research on agricultural adaptation to CCV.

1.1.1 The Socio-Economic Systems of Agriculture and Their Components

It is important to understand that there are many socio-economic systems of agricultural production. The basic components of a socio-economic agricultural system are: the key motivational forces behind each socio-economic system of agricultural production (e.g. subsistence farming and providing food to the family; traditional family farming with its emphasis on providing agricultural products for the local and regional markets, as well as other markets; capitalist or productivist farm systems focused on generating substantial profits and providing agricultural products for nearby and distant markets; and various forms of cooperative farming and marketing of produce (see Malassis 1958). These different socio-economic systems of agricultural production not only vary in terms of motivation, but also in terms of the types of technologies and inputs they utilize. Naturally all of these characteristics have evolved over time at differential rates in different countries and even between different regions in the same country. Based on these different components, including the motivation for producing agricultural produce, the different stressors that are identified below can impact the systems because of the influence they have on farmer decision-making processes.

1.1.2 *The Ecosystem Characteristics of Importance to Agriculture*

Farming is closely related to the complex system of the physical environment in which it must function. This includes the climatic conditions as well as the quality of the farmland resources, the quality and availability of water resources throughout the year and the flora and fauna present in a given area. These physical characteristics can be influenced substantially by climate change including the variability of these conditions both inter-annually and during the growing season. In this book the focus is primarily on climate conditions and their variability, including throughout the growing season.

1.1.3 *The Multiple Stressors Affecting Agriculture*

It is important to identify the existence of multiple stressors in a particular region and/or country since agricultural adaptation to CCV – the result of human decision-making – can only be realistically understood in the context of all of the stressors that affect agriculture, including opportunities for change. Obviously, first and foremost, the farmer decision-makers have to appropriate the reality of CCV before we can even begin to talk about and analyze their adaptation to CCV. But even when the reality of the CCV phenomenon is appropriated and recognized, adaptation can only occur when the phenomenon is assigned a relatively high level of importance. If there are other stressors affecting the decision-making process, then the farmer may decide that some of the other stressors are more important and even more urgent than CCV at least in the short to medium term.

The principal stressors identified are:

(a) *Climate change and variability*. This stressor includes both negative impacts on current crop mixes (because of differential impacts on crop yields for instance) as well as opportunities for agriculture in some regions since changing climate conditions, notably in terms of averages, can make some areas more suitable to different crop varieties and even entirely different crops.

(b) *Competition from other regions*, *countries and sectors*. Farming systems such as traditional family farming and especially the different forms of capitalist and productivist agriculture have to take account of the competition that they face in the different markets they serve as well as from other socio-economic sectors. These farming systems do not exist in a vacuum and their farmers need to understand the competition they face and how CCV may alter their relative competitivity.

(c) *Political decisions regarding programs and actions*. Governments have often played major roles in the transformation of agricultural systems, including the encouragement and support of different kinds given to farming to become more "competitive". This includes the push for farming to move towards being more capitalist and productivist in many Western countries. Furthermore, government actions in terms of policies and programs have often produced "unintended consequences" (usually negative consequences), in large part because it is difficult to construct a policy and program focused on very specific objectives when in reality the problem being dealt with is affected by complex decision-making processes by farmers. Some of the policies and programs that have been identified as giving rise to "unintended consequences" include government supported crop insurance programs, supply management programs for certain farm products and certain types of farm subsidies.

(d) *Cultural values that influence how government is perceived as well as the roles of individuals* (*farmers and their families*). In some of the research reported on in this book, it appears that in some farm communities farmers have a greater level of respect for private sector and social sources of information than they do for government sources of information and counseling.

(e) *Technological change and the ability of farmers to access such technological changes*, *as well as any other inputs into farm production including farmland and farm labour*. The costs and availability of different forms of inputs into farming, such as farm technology (e.g. machinery, infrastructure such as silos, chemical fertilizers, pesticides and herbicides) have presented particularly difficult situations for farmers to integrate certain inputs into their production practices in some cultural and economic contexts. On the other hand, not having access to certain types of modern farm inputs may facilitate the integration of new practices today that are more focused on sustainable agricultural practices. Another input the costs of which can be prohibitive for certain newer types of farming, such as small scale organic and sustainable agricultures, is the cost of farmland. The high costs of farmland in some areas have severely limited new entrants into farming wishing to practice new forms of farming; the same high costs of farmland in some areas have also acted as an incentive for farmers to sell their land for nonfarm purposes.

(f) *The socio-economic systems of farming*. For example, subsistence farming, family farming producing for the market, and productivist agriculture involve very different behaviour patterns on the part of farmers and their families. Furthermore, some particular types of farming, e.g. in Ontario, Canada, the Old Order Mennonite farms tend to have much lower operating costs than their neighbouring traditional family farms and much less than the more "modern" productivist (and capitalist) farms.

(g) *The level of dynamism and strength of the links between actors* (government agencies, local development officers, private companies who sometimes provide free counseling while selling other inputs) who can provide counseling to farmers and their families to help in developing and integrating adaptation strategies.

(h) *The existence of insurance programs* in some jurisdictions to compensate farmers for losses incurred as a result of certain changes in weather conditions during the crop growing season. In some jurisdictions, some of the personnel involved in such crop insurance programs also provide counseling to the farmers about improvement to their production practices. On the other hand, crop insurance programs have been criticized in some studies for encouraging mal-adaptation.

(i) *The age of the farmer and the situation regarding succession* of the farm and whether there are sons and daughters willing and desiring to take over the farm. This has often been identified as having major consequences for farmer decision-making.

(j) *The capacity of the farmer and family* (*or associates*) to assess new sources of information that can be used in productive adaptation. This also highlights the importance for some farmers and their families of having access to pertinent counseling, either from the public or private sectors, to help with adaptation. It also stresses the importance of the level of confidence that the farmers have in the different sources of counseling particularly as they relate to monitoring and assessment of the consequences of adaptation strategies to climate change and variability. This remains a challenging and crucial issue in the adaptation process. Given that the farmers must make the final decisions, it is important to understand who does the monitoring and assessment of different aspects of climate change adaptation and the level of confidence farmers have in these actors, e.g. governments and their programs, farm counsellors (sometimes paid for by farmers in local and regional associations or clubs, sometimes other actors that farmers contact to access this information) and as well the farmers themselves and their communities.

(k) *Timely results of relevant agricultural research* can greatly influence the adaptation process. For instance, the availability of more appropriate cultivars can allow farmers to benefit from the prevailing climate conditions.

1.1.4 Types of Adaptation

Adaptation strategies can involve a number of different strategies, sometimes pursued individually and sometimes involving the integration of two or more of the adaptation strategies identified below.

(a) *Modifying crop varieties to accommodate changing climate conditions*. This refers to the agricultural production mixes (crops, livestock…) that can be directly or indirectly linked to climate conditions and changes, as well as many of the other stressors (including opportunities) such as competition from other regions, countries and continents.

(b) *Modifying inputs used in agricultural production systems*, e.g. more or less fertilizers, changes in the types of fertilizers, modifying the utilization of pesticides and their types

(c) *Water management strategies and pertinent infrastructure development* (e.g. drainage improvements)

(d) *Financial and farm management adjustments*
(e) *Modifying management practices*
(f) *Changes in marketing strategies*, e.g. choice of markets to be served and how to integrate with them

In addition to these various aspects of farm adaptation, there are two other general considerations to be taken account of in undertaking research, including action research, on farm adaptation to CCV.

First, it is important to understand the spatial scale at which adaptation is being investigated: country, region, local municipality or community. The broader the geographic scale involved, the greater the challenges of developing pertinent adaptation counseling simply because the broader the scale the greater the probability of having to deal with significant territorial differences in farm production systems, ecosystem characteristics and pertinent adaptation strategies.

Second, it is worth underscoring the importance of understanding the difference between the time frame regarding climate change and the decision-making time frame for farmers. Farmers – and more so in some cultural, economic and political environments than others – can often be more preoccupied with the short term survival of their farm and family than with what they perceive to be the longer term preoccupations of CCV. This means that their survival which is necessary to deal with before tackling CCV may require them to devote considerable energy to tackling other stressors in the short term.

Finally, it is important to stress that understanding the impacts of CCV and the effects of different adaptation activities remains a challenging and crucial issue in the adaptation process. Some of the most important challenges relate to ensuring that the farming communities involved really appropriate the significance of CCV and then integrating the local and traditional knowledge that farming communities possess into both the modeling of climate change scenarios as well as into the processes of development of adaptation strategies. It is also important to stress that once adaptation strategies have been adopted by farmers, it would be very useful to put in place a continuous monitoring and assessment process of the effectiveness of the adaptation strategies, using both the modeling approaches and those based on evaluations by the farmers involved.

1.2 Approaches to Research in Order to Understand Adaptation to CCV

1.2.1 Comparative Research and Other Comparative Information of Use to Farmers

To start off, we would like to emphasize the importance of comparative research and studies as a means of highlighting both the significant differences between communities, regions and countries in terms of the phenomena of CCV as well as the fundamental human side of the equation of adaptation to CCV. This implies that it is not reasonable to parachute programs to support adaptation to CCV that might work well in one country or region to another country or region without understanding the fundamentals of adaptation and its social, cultural and even political foundations. For instance, adaptation can be seen as being comprised of different "innovation strategies" for the farmers concerned and depending upon the costs of such strategies to the farmer and their values, some adaptation strategies could not even be contemplated.

This is reflected in this book by the organization of the book into two Parts (Part I: Canada and France; and Part II: Africa). Each chapter does not generally engage directly in comparative analyses, though Vasseur and You (Chap. 11) do draw some comparisons. However, readers can go through the chapters, and using the conceptual framework presented above can already begin to draw conclusions about the differences between the different regions and countries dealt with by different authors.

1.2.2 The Different Research Approaches

A number of different but generally complementary research approaches are presented in this book:

(a) Understanding climate conditions with a classical approach which involves presenting the climate characteristics for specific regions or countries, and letting the farmers and readers draw conclusions regarding the relevance of these parameters to farming in the region or country (e.g. Chap. 9 by Bellichi).
(b) Understanding the broader context in which adaptation to climate change and variability must take place. Several of the Chapters have integrated this issue into their chapters. For instance, Soulard and Meynard in Chap. 8 tackle in detail the context for understanding adaptation to climate change and variability in France.
(c) Climate change modeling can be a valuable tool for undertaking research on adaptation to CCV. However, it must be developed and used in a constructive manner (the Université de Montréal research teams used different climate change models to develop climate scenarios (Chap. 3 (Daouda and Bryant); Chap. 4 (Délusca and Bryant)), while in Chap. 10 (Sarr et al.) there is a related focus on a statistical model linking indicators of rainfall with crop yields. The assessment of climate change impacts on agriculture through the analysis of future climate scenarios linked to the modeling of crop yields in specific regions can be seen as a useful prerequisite in order to be able to offer a range of effective adaptation strategies for farmers to be able to assess and develop their own adaptation strategies. For instance, the Université de Montréal research teams presented climate scenarios for their broad study regions to groups of farmers to get the farmers present to react to the parameters used

in the climate scenarios and on several occasions the teams adjusted the scenario parameters to bring them closer to the farmers' perceptions of their farming realities. This information was then used in some projects for modeling the economic parameters associated with different adaptation strategies, particularly in relation to crop mixes (Chap. 5 by Thomassin and Ning).

(d) The use of insurance data (compensations and the reasons for requesting compensation from the insurance programs (principally the FADQ, or the Financière Agricole du Québec (the Agricultural Financial Corporation of Quebec), was essentially based on detailed data provided by the FADQ at the level of the municipalities or regions in the research programs) to help farmers appropriate the reality of the phenomena of CCV over 15–30 year periods, depending on data availability).

(e) The use of surveys of farmers and focus groups of farmers, and also sometimes focus groups involving representatives of other actors such as the FADQ, ministries of agriculture and watershed management organizations (Chap. 2 by Brklacich and Woodrow; and Chap. 5 by Thomassin and Ning).

(f) The use of surveys and focus groups to place the emphasis on the local knowledge of farmers and other actors (in most of the chapters dealing with Canada (Quebec and Ontario) (Chaps. 2, 3, 4 and 5 (already referred to) and Chap. 6 (Choquette, Milot and LePage) and particularly in relation to traditional knowledge in Africa (Chap. 12 (Tremblay) and Chap. 13 (Feumba et al.)).

(g) Ensuring that the research underscores the importance of understanding the social systems in which farmers and other actors function. This approach can be used to show how adaptation strategies can be diffused through farming communities (Chaps. 10, 11, 12, and 13) and particularly how this diffusion can be represented as an innovation diffusion process (Chap. 3 by Doauda and Bryant).

We would like to stress that much of the research discussed in this book is the result of long term research programs with origins going back over some 25 years. Thus some of the research approaches have shifted over time with more and more emphasis being given to the importance of social systems and understanding how these function particularly in terms of the use of traditional and local knowledge. It is important to investigate in any constructive research project with a practical orientation how this local and traditional knowledge can be integrated into various modeling exercises both in relation to climate change and the economic structures and dynamics of farms.

References

Bryant, C. R., André, P., Provençal, D., Singh, B., Thouez, J.-P., & El Mayaar, M. (1997). L'adaptation agricole aux changements climatiques: Le cas du Québec. *Le Climat (Numéro spécial: Les défis des changements environnementaux à l'échelle planétaire), 14*(2), 81–97.

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

Bryant, C. R., André, P., Thouez, J.-P., Singh, B., Frej, S., Granjon, D., Brassard, J.-P., & Beaulac, G. (2004). Agricultural adaptation to climatic change: The incidental consequences of managing risk. In D. Ramsey, C.R. Bryant (Eds.), *The structure and dynamics of rural territories: Geographical perspectives* (A Collection of Essays from the Rural Geography Study Group, Canadian Association of Geographers, 2001 and 2002 Annual Meetings), Rural Develop Institute, University of Brandon, pp. 260–271.

Bryant, C. R., Singh, B., Desroches, S., Délusca, K., Savoie, M., Da Costa, E., Côté, S.-O., Thomassin, P., & Baker, L. (2007). Adaptation of farming and farming communities to extreme climatic events: Looking at the past to understand the adaptation to climate change. In T. Sorenson (Ed.), *Colloquium Proceedings, IGU CSRS* (pp. 70–79). Armidale: University of New England, Australia.

Bryant, C. R., Singh, B., & Thomassin, P. (2008) *Evaluation of agricultural adaptation processes and adaptive capacity to climate change and variability: The co-construction of new adaptation planning tools with stakeholders and farming communities in the Saguenay-Lac-Saint-Jean and Montérégie Regions of Québec*. Ottawa: Research Report for project A1332, submitted to Natural Resources Canada, CCIAP, 2008, 42 pp, and 300 pp in appendices.

Bryant, C. R., Sanchez, N., Delusca, K., Daouda, O., & Sarr, A. (2013, March). Metropolitan vulnerability and strategic roles for periurban agricultural territories in the context of climate change and variability. *Cuadernos de Geografia, 22*(1), 58–68.

Malassis, L. (1958). *Économie des exploitations agricoles: essai sur les structures et les résultats des exploitations agricoles de grande et de petite superficie*. Paris: A. Colin, École Pratique des Hautes Études.

Singh, B., Bryant, C. R., El Maayar, M., André, P., & Thouez, J.-P. (1997). Climate change and variability and adaptation in agriculture, Quebec. In *Proceedings of the binational symposium: Adapting to climate change and variability in the Great Lakes-St. Lawrence Basin*. Ottawa: Environment Canada.

Singh, B., El Maayar, M., André, P., Bryant, C. R., & Thouez, J.-P. (1998). Impacts of a GHC-Induced climate change on crop yields. Effects of acceleration in maturation, moisture stress and optimal temperature. *Climatic Change, 1998*, 51–86.

Christopher R. Bryant received his doctorate in 1970 at the London School of Economics and Political Science (LSE), London. He was progressively Assistant, Associate and Full Professor in Geography at the University of Waterloo (1970 to 1990), then Full Professor in Geography at the University of Montréal (1990 to 2014), and is now Adjunct Profesor in Geography at the University of Montréal and also in the School of Environmental Design and Rural Planning, University of Guelph. He is one of the international leaders in research on urban/periurban agricultures (Canada, Western Europe and elsewhere), and he is also a recognized leader in the domain of adaptation of human activities (and especially agriculture) to climate change and variability, in local and community development, and in the strategic planning for local and regional development for and by citizens.

Kénel Délusca is an agronomist engineer by training; his PhD is in Physical Geography (University of Montreal) with a specialization in climatology. Dr. Délusca was project coordinator and a postdoctoral fellow at the Laboratory of Sustainable Development and Territorial Dynamics within the Department of Geography (University of Montreal) where he worked on the assessment of the impacts of climate variability and change on agriculture in Quebec and Eastern Ontario and on the co-construction of adaptation policies and programs. Between 2013 and 2015, he was a visiting scholar at the Geography Department of Université de Montréal and Research Engineer at the French National Institute for Agricultural Research (INRA). Dr. Délusca has published several

scientific papers and produced several reports related to the assessment of climate change impacts on agriculture and coastal zones with a focus on water issues. He is actually Adjunct Professor at the Institut des Technologies et des Études Avancées d'Haïti (ISTEAH) and Team Leader of the Technical Assistance to an European Climate Change-funded project in Haiti. His research interests are: climate change vulnerability assessment, high-resolution climate scenario elaboration, crop modeling, climate change policy, environmental evaluation, and multi criteria analysis.

Mamadou Adama Sarr received his PhD from the Université Jean Moulin Lyon III, France. His current affiliation is as a Researcher with the Centre de Suivi Écologique, Dakar, Senegal. He was also a post-doctoral Fellow in the Laboratory of Sustainable Development and Territorial Dynamics, Geography at the Université de Montréal. His research interests are in climatology, climate change, regional climate modeling, climate variability and extremes, Geographic Information Systems and Socio-Ecological Systems.

Part I
Canada and France

Chapter 2
Agricultural Adaptation to Changing Environments: Lessons Learned from Farmers in Eastern Ontario, Canada

Mike Brklacich and Maureen Woodrow

Abstract Agriculture exists in dynamic environments where change is normal. All facets of agri-food systems are constantly exposed to these changes and, when necessary, make adjustments. This study builds on our growing understanding of farm-level adaptations in uncertain environments. It grapples with agriculture change in general and, more specifically, framing climatic change adaptation within the complex and dynamic environments that farmers negotiate on a daily basis. Engagement with the farming community was in conjunction with the Dundas County Federation of Agriculture, occurred during 2009–2013, and included the co-hosting of two focus group meetings plus the administration of 42 in-depth interviews. Many changes in Dundas County over the past 30 years mirror broader sectoral trends, including a decline in the number of farms (−40 %) coupled with increases in farm size (+61 %) and the age of farm operators (+14 %). One significant difference however is that farming continues to be the main economic activity in Dundas County with only a slight decline (−3 %) in the overall area devoted to farming. The continued strength of farming reflects the willingness and ability of farmers to embrace technological improvements as well as consolidate farm operations in order to manage costs and buffer uncertainties. Farmers are confident they can manage anticipated changes over the next two decades but are concerned with potential negative impacts associated with more government regulations and farm succession. Climate change, especially increases in the incidence of extreme events, is viewed as another but manageable uncertainty that will need to be factored into longer-term decisions.

Keywords Adaptation • Climate change • Community engagement • Eastern Ontario

M. Brklacich (✉) • M. Woodrow
Department of Geography and Environmental Studies, Carleton University, Ottawa, ON, Canada
e-mail: mike.brklacich@carleton.ca; mwoodrow@sympatico.ca

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_2

2.1 Introduction

Research into agri-food and climate change relationships has flourished since the early 1980s (for example, see Beddington et al. 2011; Easterling et al. 2007; Kang et al. 2009; Parry 1990; Rosenzweig and Parry 1996) and has been characterized by at least three distinct but increasingly interconnected frameworks[1].

Much of the early work followed ***impact-based approaches***. This work routinely commenced with a specification of scenarios for global climate change that were derived from either historical analogies or climate forecasts generated by general circulation models. Then various downscaling techniques were employed to transform global forecasts into regional agro-climatic scenarios, which in turn provided inputs to crop productivity and land suitability models. The main contributions of this research was, and continues to be, a better understanding of how adjustments in specific climate parameters (e.g. heat accumulation during the frost-free season, timing and total amount of precipitation) might alter crop yields and the suitability of regions for commercial agriculture.

Response-based approaches complement impact-based approaches by considering potential adaptations by agriculture to future changes in climate. The starting point for these two approaches are similar (i.e. scenarios for broad scale climate change) but the response-based approach allows for potential adaptations by agriculture to climate change. Possible adaptations draw on the agri-food sector's history of adjusting to changing conditions, incorporating adaptations such as but not limited to employing crop varieties that are better matched with an evolving climate (e.g. more drought resistance varieties), more effective use of on-farm technology (e.g. irrigation to offset moisture deficit) and crop insurance to minimize the financial impacts of years with lower than expected yields.

Two over-arching characteristics of these two approaches are they are based on a series of interconnected models that tend to isolate agriculture from the myriad of factors that routinely influence the agri-food sector and farmers are to a large extent excluded from the research process. Hence it should not be surprising that these approaches have been instrumental in the provision of initial assessments from agro-ecology perspectives but they have not been able to capture the social and economic spaces in which farms operate. It is in response to this limitation that the third approach, a ***vulnerability-security approach***, has emerged (Fig. 2.1). An important distinguishing feature of this approach is its attention to positionality from two perspectives. First, the approach carefully situates farming systems within the wider range of societal and environmental changes that influence agriculture and thereby breaks away from the previous approaches that effectively treat climate change in isolation. In fact, the vulnerability security approach does not assume climate change will be a major influence on the future of farming systems but rather it attempts to situate climate change amongst other forces that will determine the

[1] The review of the approaches summarized below is derived from Brklacich et al. (2000) and Brklacich et al. (2007).

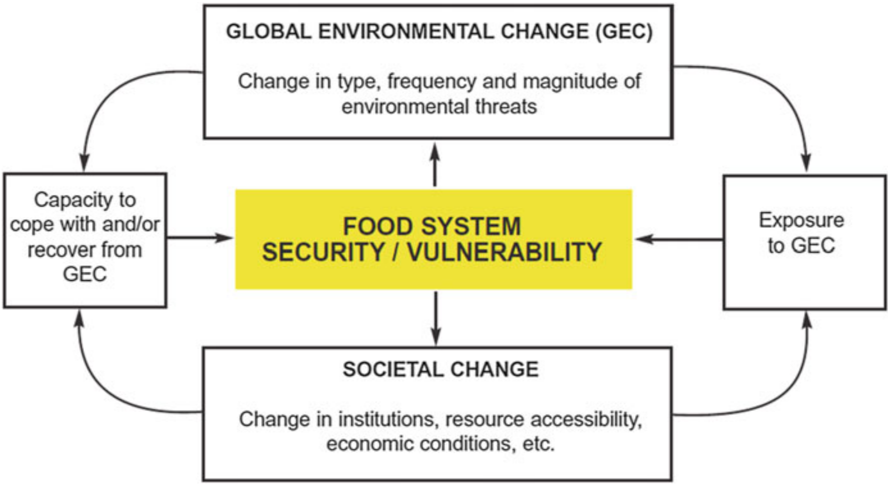


Fig. 2.1 A food system vulnerability-security approach to assess climate-agricultural relationships (Derived from Brklacich 2006, Ingram et al. 2005)

trajectory of agriculture. The second aspect of positionality is the adoption of "lives lived" approach (for example, see Head et al. 2011). That is, it requires an integration of farming communities into the research process in order to gain a better understanding of the driving forces that influence the sector's current capacity (or incapacity) to manage change in an increasingly uncertain future.

The research presented in this Chapter was conducted in contemporary rural eastern Ontario, Canada, and is situated within the emerging field of vulnerability-security approaches to understanding climate change – agriculture relationships. It builds on our growing understanding of farm-level adaptations in uncertain environments. It grapples with agriculture change in general and, more specifically, framing climatic change adaptation within the complex and dynamic environments that farmers negotiate on a daily basis. In addition to providing insight into the lives lived by farmers in eastern Ontario, it also sheds light on how we might advance this field of research.

2.2 Setting the Context: Agriculture in Dundas County, Ontario

Dundas County is located in eastern Ontario along the north shore of the St Lawrence River and within a 2-h drive of major urban centres including Ottawa and Kingston. The natural resource base is well suited to commercial farming. About 73 % of the County's total land base of 102,300 ha is well suited for commercial agriculture and another 19 % is suitable for pasture crops (Hoffman and Noble 1975). Weather in the County is also well suited to commercial agriculture. The average annual daily temperature is 6.6 °C, with a daily average of

Table 2.1 A profile of Dundas County, Ontario: 1981–2011

	1981	1991	2001	2011	1981–2011 % change
Population					
Total	17,457	18,945	20,890	22,019	+26
% 20–44 years	34	37	31	26	−23
% +65 years	13	15	15	19	+46
Farms					
Number	949	804	695	570	−40
Farmland (ha)	71,566	68,843	71,251	69,235	−4
Ave farm size (ha)	75	86	103	121	+61
Cropland					
Land in crops (ha)	41,770	48,333	55,152	55,920	+34
% of farm in crops	58	70	77	81	+38
Dairy					
Producing units			223	142	−36
Production (kl)			94,618	82,382	−13
Production (kl/unit)			424	580	+37

Source: Derived from: Statistics Canada and Dairy Association of Ontario

15.6 °C for the April to September period. Annual rainfall averages 756 mm with about 70 % occurring between April and September. Summer droughts are a periodic problem with the most recent drought occurring in mid-2012[2].

Agriculture in Dundas County has undergone several transformations over the past 30 years but farming remains viable and the main economic activity for the County (Table 2.1). As in other agricultural regions of Ontario, the sector has become more concentrated and intensive. While the total farmland area has remained relatively constant (−4 %), there has been a significant decline of the total number of farms (−40 %) and overall the average farm size has increased by 61 %. As part of this transformation, farmers have put more land under crops and less land into pasture. The total area of Dundas County under crops has increased by 34 % over the last three decades and in 2011 less than 20 % of each farm on average was used for non-cropping activities.

Although dairy remains the primary livestock activity, similar trends are occurring in this sector as well. That is, the total number of dairy farms has decreased at a faster rate than overall milk production for the county, with average milk production per active unit increasing by 37 % over the last decade. It would appear that opportunities to further intensify agricultural land use in Dundas County are quite limited but nevertheless agriculture remains the economic backbone.

Unlike many other rural areas in Ontario and in Canada more generally, the population in Dundas County has recently increased. Total population in the County has increased steadily over the past three decades. However much of this

[2] Derived from Canadian Climate Normals 1981–2010 Station Data for Kemptville, Cornwall and Russell Ontario. Data accessed from http://climate.weather.gc.ca/climate_normals/index_e.html.

increase is attributable to an aging population and the out-migration of younger adults in the prime of their working life is a growing concern. While these demographic trends are a concern, the overall magnitude of these shifts in Dundas County is considerably lower than in other rural areas in Canada (Troughton 2004; Wallace and Brklacich 2010), suggesting the rural community remains relatively intact within Dundas County.

2.3 Engaging the Farming Community in Dundas County

The starting point for the empirical component was establishing a research collaboration with the Dundas Federation of Agriculture (DFA)[3], the largest agricultural organization in the County with over 400 members. DFA was the focal point for the research engagement that occurred between 2009 and 2013 but it is also important to recognize these collaborations also involved two municipalities, North and South Dundas, the South Nation Conservation Authority and several farmers and farm businesses in the County. Overall, these collaborations were based upon the following three guiding principles.

2.3.1 Collaboration Was Central to the Project

The entire project was based upon a collaborative model that facilitated interactions between the research team and farming communities in Dundas County. This relationship was built slowly and purposively, and the respect that DFA has earned as a prominent and respected advocate of commercial agriculture and rural life was critical to developing a wider set of engagements. It was this partnership that influenced the research design and project implementation.

2.3.2 Sharing of Information

Sharing of information was established from the outset as a central aspect of the partnership. Sharing took place in several ways. For example, one of the first project activities was the preparation of a background report that compiled a wide range of environmental and socio-economic data about the County into a single compendium. This was useful in its own right as it pulled together data from a wide variety of venues into a single report that allowed several organizations to easily access what had previously been somewhat difficult to locate and collate. In addition, a

[3] Information about DFA is available from http://www.dundasagriculture.com/.

draft version of the background report was shared with DFA members in advance of its release to ensure accuracy and to confirm the report's structure suited a wide variety of needs. This approach of seeking input by DFA members on the research design and draft reports was replicated several times throughout the project and was as much a trust building exercise as it was an information sharing process.

2.3.3 Climate and Climate Change Are But One Factor

In the spirit of understanding uncertainties that routinely enter into farm-level decision making, the research process purposively de-emphasized the climate change component of the project during the initial phases of the project. That is, we elected to avoid a traditional top-down approach that commences with the specification of scenarios for climate change and to start each form of community collaboration with efforts that led to a deeper and more nuanced understanding of the evolution of factors that are influencing and expected to influence agriculture in the County. This approach allowed us to emphasize the importance of employing a "lives lived approach" and to carefully situate climate change as one of several factors that might enter into farming decisions over the medium to long-term.

2.4 Research Design and Implementation

The project was implemented over a 3-year period using the six steps summarized in Table 2.2. Each step is presented as a separate entity in Table 2.2, with each step relying on information provided by an earlier step or steps. This iterative process reflects the overall commitment to collaboration and information sharing. Several of the steps included reviews of preliminary results and/or proposed next steps. This approach was an integral part of building trust between the researchers and key actors in Dundas County, and allowed the project to adjust to changing conditions throughout the project's life span.

2.5 The Recent Evolution of Agriculture in Dundas County

Agriculture in Dundas County has evolved considerably over the past few decades, it remains healthy and it is much more intensive (Table 2.1). When asked about recent changes in agriculture, farmers and farm service representatives highlighted three themes (Table 2.3). First and foremost, it is important to recognize farming has embraced science and technology, including advances in crop science with new seed varieties and livestock technology. Recent shifts in agriculture in Dundas County have to a large extent been supported by a significant increase in many

Table 2.2 Implementing the research project

Project activity	Timeline	Key features
Exploratory meetings	Late 2010	Informal meetings with key informants leading to the identification of contemporary agricultural and rural planning issues
Background report preparation	2011	A compendium of environmental and socio-economic data (e.g. land resource capability, farming and demographic trends)
Focus group meeting 1	Spring 2011	Engagement of representative farmers, public officials and farm business representatives in reviews of and revisions to (i) the background report and (ii) questionnaire probing agricultural adaptation
Intensive questionnaires	Late 2011–Early 2012	Questionnaire probing (i) recent farm-level adaptations and (ii) visions for the future of agriculture was administered in person to 28 farmers and 14 agricultural service representatives
Focus group meeting 2	Late 2012	Review and revisions to preliminary findings with representative farmers, public officials and farm business representatives
Final report preparation	2013	Redrafting of preliminary report in response to the input received at focus group meeting 2

Table 2.3 Recent evolution of farming in Dundas County

Rank	Change and key quotes	Questionnaire results N=	%
1	Science and technological improvements	19	45
	The way people farm has changed. We are looking more into the science of farming rather than just making a living		
	If agricultural businesses provide high tech equipment, they require highly trained sales agents and technicians to support the farmers		
2	Farm consolidation and costs	18	43
	There are fewer and bigger farms. Bigger are more efficient. . . . You have to work smarter		
	Capital cost of getting into agriculture is more difficult especially for young people to get started		
3	Land management	17	40
	Tile drainage is the biggest change in the area in the past 30–40 years. Our crop yields have increased		
	No till because it does not take as much fuel and saves time		
	Precision farming is a major change in farm technology		

technologies that are now commonplace. At the farm level, these new technologies have increased the range of crops that can be grown and the conditions under which they are grown (e.g. planting earlier). Farmers stressed that new technologies improved efficiencies and required new skills focusing on the use and operation of advanced agricultural management methods. It was also noted these efficiencies do not always offset increased costs and new technologies do not always remove the economic challenges of farming, and the economics of farming continue to be a challenge. Emerging over the last decade are technological advances such as precision farming, and robotic and fully automated milking. The success that many farmers in the county have recently enjoyed have been supported by many factors such as increases in education levels and better business management skills as well as the farm service sector recognizing new opportunities and the importance of supporting high tech agriculture with better equipment and advice for farmers.

Farm consolidation and changes in the cost of farming ranked second as past drivers of change. Capital investments needed to run a farm have been increasing which in turn adds to the complexity of farm management and succession planning. The lack of adequate public infrastructure in rural areas continues to be a barrier to expanding farm operations. Farmers expressed concern that improvements to hydro, gas and roads have not kept pace with the needs of larger farms. For example, natural gas, the least expensive fuel, is not readily available to rural areas and rural roads are often too small for modern equipment. Other farmers felt that improvements to agricultural infrastructure such as grain drying and storage facilities had benefited from government programs.

The agricultural business service sector representatives highlighted another dimension of consolidation and noted many farm businesses had modernized, resulting in fewer but larger outlets. In addition, the demand for newer high tech equipment requires more highly trained sales agents and technicians. From the perspective of the owners of farm service businesses, there was now a greater need to efficiently manage parts inventories and to recognize that many uncertainties beyond the control of the agricultural sector (e.g. fluctuations in the Canadian dollar) impose substantial challenges for growth. The main point is that living with uncertainty has become part of day-to-day living for the entire agricultural community in Dundas County.

Land management techniques have also emerged as a key theme that has shaped the resent evolution of agriculture in the County. Tile drainage was highlighted as a major shift in the management of agricultural lands that started with a major increase in subsurface drainage in eastern Ontario in the late 1960s and 1970s. More recently, the emphasis has shifted away from tilling new fields towards reducing the spacing of drains in existing fields. No till and precision farming are also of growing importance. These trends in land management further reinforce the notion that adaptation is a normal part of being a farmer in Dundas County.

2.6 Envisioning the Future of Agriculture in Dundas County

Looking forward, the majority of farmers were optimistic about the future. While recognizing that several uncertainties will create new challenges, most farmers expressed willingness and perceived an ability to make changes and adapt as necessary. At the same time, they accepted that productivity and/or the size of farms would have to increase further. Not surprisingly, there was less of a consensus about the future challenges than the past changes, and responses about key changes into the future were somewhat more speculative (Table 2.4).

Many farmers emphasized that the trend towards fewer farmers producing more food will continue. Some farmers envisioned a future where corn production in the County would double in response to more diversified markets for corn-related products such as cosmetics and other personnel care products, paper, foods, beverages, textiles and fabrics. On the other hand, possible increases in food prices may

Table 2.4 Moving forward: envisioning future farming in Dundas County

		Questionnaire results	
Rank	Change and key quotes	N=	%
1	Farming operations	17	40
	I am getting bigger into crops. The kids do not want to do labour especially for dairy		
	The future is good. There is an opportunity to expand down the road. The farm must grow		
2	Farm value and cost increases	13	31
	The continuation of the cheap food policy will restrict the capacity of farmers to innovate and adapt. . ."		
	Our farm is our retirement – how do we get out enough to retire without jeopardizing our son's future chance of success?		
3	Government regulations	11	26
	Learning to comply with new regulations means more time and workload and especially more paper work		
4	Viability of small farms	10	24
	How can you get a small family farm to continue without getting into mega farms? *In our situation, sons are not interested in farming – there is too much uncertainty*		
	Need lots of capital to start or you have to use a job if you are starting a small farm? *I am not big enough for a young person trying to make a living – you would need to start part-time*		
5	Technology	10	24
	Farmers need to be more knowledgeable and have to work smarter with new technologies		
	There is a need for more education and outreach to apply technologies at the farm level		

be required to offset rising on-farm costs in fuel and labour, and therefore production increases may not translate into improved profitability for farmers. At the farm level, it was stressed that better planning and information would be required as an input into advanced technologies such as precision farming. Overall many challenges for farming are expected and Dundas farmers are confident of their abilities to continue to adapt to change.

Despite the optimism, several farmers in Dundas County also recognize many challenges. These challenges were framed in several ways, such as keeping costs down and a commitment beyond the business side of managing a farm in order to provide food at a reasonable price. Another aspect is the commitment over the long term and the future of the family farm. Uncertainties about the future of smaller farms seems to be different than for larger ones. The ability of smaller farms to weather storms appears to be diminishing, suggesting the consolidation and the intensification process that have characterized farming over the past 20 years, will continue into the near future.

Government regulation of farming is a growing issue for area farmers, and touched on many themes such landowner property rights, payment for easements and additional administrative costs for farmers. The expansion of a wide range of government regulations over the past 10 years, including regulations that are of direct consequence to agriculture (e.g. the Nutrient Management Act and Environmental Farm Plan) as well as non-agricultural regulations (e.g. Labour and Safety Regulations, the Species at Risk Act) are expected to become more prominent and potentially more challenging in the future. The growth in regulations is expected to add to the administrative load and costs of farming and additional regulations are viewed as a major constraint that could impede the growth of farming over the next two decades.

There was no uncertainty regarding the place of technology in the future of farming in Dundas County. As in the past 20 years, technology is expected to play a key role in adaptation to change but the breadth of technologies that are expected to become part of farming on a routine basis is expected to expand quickly over the next 20 years. Farmers expressed confidence that they would become savvier in the use of social media to get the message out about farming and that farm organisations will need to focus more on educating the urban public on the source of their food and the realities of modern farming. With easier and wider access to new technologies and social media, farmers highlighted that more education and improved skills development would become more commonplace on the farm.

In summary the future is promising for the farm community in Dundas County. Trends towards consolidation and intensification are expected to continue. The value of the farm and the costs of being a farmer are expected to increase but farmers are very aware of their role in feeding the world and keeping costs at an affordable level for the expanding population. Government regulations however represent a barrier and farmers felt it was a key issue moving forward. "*Our biggest challenge is keeping the government out of it*" was a constant refrain.

2.7 Climate Change and the Future of Agriculture in Dundas County

The framing of future climate change and understanding its role in farming cannot be divorced from the overall health of farming in the County and the sector's demonstrated track record of adapting to uncertainty. Current farmers have used their resources and ingenuity over the past 30 years to modernize, to maintain the economic viability of the sector and to guard the rural-way of life. It is in this context that it is not surprising that the vast majority of Dundas County farmers are not overly concerned about climate change. This is further confirmation that Dundas County agriculture is robust and farmers are confident they can manage climate change just as they can respond effectively to other changes (Table 2.5). In addition, the majority of farmers in Dundas County framed climate change as being less of a challenge than other concerns including a growing array of public policies that will impose more constraints on farming and ensuring younger family members are able to make a living from farming over the long term (Table 2.6).

Table 2.5 Preparedness of farms in Dundas County for climate change

	Questionnaire results	
Preparedness and key quotes	N=	%
Farms are well prepared	37	88
We'll be fine, we'll make changes as necessary		
We can't control the climate change, we have to adapt		

Table 2.6 Situating climate change amongst other uncertainties

	Questionnaire results	
Climate change compared to other challenges and key quotes	N=	%
Policy is more challenging than climate change	40	95
Our biggest challenge is to keep government out of it.		
We have to take advantage of all new government programs that help us with electricity such as solar, wind and biomass		
Succession is more challenging than climate change	24	57
Passing the farm on is a lot harder than climate change		
...succession is intensive and an expensive process...especially if the goal is for everyone to live reasonably		

2.8 Lessoned Learned

> *... you have to think big and think outside the box. Be innovative and most of all love it. There has to be a passion. ... In this business it is feast of famine*

This quote, offered by a Dundas County farmer during the administration of intensive questionnaires in 2011–2012, captures much of what was learned during this research initiative. While most farmers as well as representatives of public agencies and the private sector are quick to mention the economics of farming and the multitude of challenges that influence the “bottom line”, farming is much more than an economic activity. It is a way of life, it is a passion, it is a commitment to provide safe and nutritious food to an increasingly urban world, and perhaps most of all, it is about the future as well as the past and the present. And it is this context that there are at least two meta-lessons that emerge from this project.

The first relates to the engagement of rural communities in general and active farmers specifically. In this project, close collaboration with DFA was the centrepiece of the entire research project. DFA is a well-respected actor within the farming community and its enthusiasm for the project facilitated collaborations that drew in farmers from across the County as well as representatives from the public and private sectors. This, in turn, enable the “lives lived” approach to flourish and the project team to gain deeper and clearer insights into the challenges that farmers have endured and their ability to take on new challenges. And with over 400 members in a County that relies on 570 farms as the mainstay of its economic and cultural activities, we clearly had access to the vast majority of farmers in the County. Nevertheless, one cannot ignore DFA members are the survivors and, in some ways, represent a unique cohort. The number of farms in Dundas County shrank by 40 % between 1981 and 2011, and we had the privilege of engaging with the majority of the 60 % who survived. Farmers exit farming for many reasons, including a planned and purposeful retirement. And several DFA members are retired farmers and this project benefited tremendously from their life histories. But who was not engaged in the project, and how might have their experiences altered our findings? It would seem there are least two groups who were unintentionally overlooked here. One is the minority of current farmers who choose to not affiliate with DFA. At this time, we do not know their reasons for opting out, suggesting more robust engagement strategies should devote some effort to identifying and collaborating with this important cohort. The second group is a subset of the 40 % of farmers who exited farming over the past three decades and are no longer part of the DFA family. There is some evidence this subset is comprised, in part, of farms and farmers who did not survive, the ones who were not able to rise to the challenge of farming in an increasingly urban world fraught with more uncertainty. Exiting from specific businesses in an increasingly connected world is not a phenomenon that is unique to farming but these departures are routinely under stressed conditions. The passion that many Dundas County farmers have for farming coupled with an aging farm population and farmers routine citing of intergenerational succession as one of the most challenging uncertainties they will face, suggests the next generation of climate change – agricultural adaptation research ought to develop strategies that allows for former farmers to be more engaged in the research process.

The other major lesson relates to positionality. In this study, the majority of farmers framed climate change as another uncertainty that ought not to be considered in isolation. Their collective experience in farming, the commitment and passion to gradually passing on a farm that was thriving to the younger generation, and access to resources, including advanced technologies, underpinned the view that climate change was not an especially daunting challenge and that it could be managed in conjunction with other anticipated changes. It is this context that it would, by extension, be inappropriate to dismiss climate change as an unimportant challenge. The confidence expressed by farmers in this study hinged upon their past successes and continued ability to recognize signals of change and to adapt as needed. In sum, this shines a light on the complexity and dynamics that routinely define contemporary agriculture and why farmers routinely make decisions in response to multiple stressors and opportunities. Farming today, and into the future, is about positioning the farm within an increasingly complex world where farmers grapple on a daily basis with concerns that span local concerns (e.g. making a decision to upgrade infrastructure on a specific farm) through to global issues (e.g. how to feed nine billion people in 2050). Carefully situating farming in a particular location amongst these compelling and wide ranging issues is clearly a necessary component of our efforts to better understand agriculture's capacity to adapt to future uncertainties such as but not limited to climate change.

Acknowledgements The authors wish to thank the Dundas Federation of Agriculture and the broader agricultural community in Dundas County for their enthusiasm and support throughout the project. This work was facilitated by financial support from Canada's Social Science and Humanities Research Council under its Strategic Research Grant – Canadian Environmental Program, with Christopher Bryant as the principal researcher.

References

Beddington, J., Asaduzzaman, M., Fernandez, A., Clark, M., Guillou, M., Jahn, M., Erda, L., Mamo, T., Van Bo, N., Nobre. C. A., Scholes. R., Sharma. R., & Wakhungu, J. (2011). Achieving food security in the face of climate change: Summary for policy makers from the Commission on Sustainable Agriculture and Climate Change. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen. Available online at: www.ccafs.cgiar.org/commission

Brklacich, M. (2006). Advancing our understanding of the vulnerability of farming to climate change. *Die Erde, 137*, 181–198.

Brklacich, M., Bryant, C., Veenhof, B., & Beauchesne, A. (2000). Agricultural adaptation to climatic change: A comparative assessment of two types of farming in central Canada. In H. Millward, K. B. Beesley, B. Ilbery, & L. Harrington (Eds.), *Agricultural and environmental sustainability in the new countryside* (pp. 40–51). Halifax: Saint Mary's University Press.

Brklacich, M., Wall, E., Smit, B., & Wandel, J. (2007). Impacts-based approaches. In E. Wall, B. Smit, & J. Wandel (Eds.), *Farming in a changing climate: Agricultural adaptation in Canada* (pp. 13–31). Vancouver: University of British Columbia Press.

Canada, Statistics Canada Census of Population 1981, 1991, 2001 and 2011. Ottawa.
Dairy Association of Ontario. (2012). *Dairy statistical handbook 2010–2011* (27th ed.). Mississauga: Dairy Farmers of Ontario.
Easterling, W., Aggarwal, P., Batima, P., Brander, K., Erda, L., Howden, S., Kirilenko, A., Morton, J., Soussana, J.-F., Schmidhuber, J., & Tubiello, F. (2007). Food, fibre and forest products. In M. Parry, O. Canziani, J. Palutikof, P. van der Linden, & C. Hanson (Eds.), *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change* (pp. 273–313). Cambridge: Cambridge University Press.
Head, L., Atchison, J., Gates, A., & Muir, P. (2011). A fine grained study of the experience of drought, risk and climate change among Australian wheat farming households. *Annals of American Geographers, 101*, 1089–1108.
Hoffman, D., & Noble, H. (1975). Acreages of soil capability for agriculture in Ontario. Toronto: Ontario Ministry of Agriculture and Food. Report No.8,
Ingram, J., Gregory, P., & Brklacich, M. (2005). Global environmental change and food systems: Science plan and implementation strategy. Wallingford, Earth System Science Partnership Report No.2.
Kang, Y., Khan, S., & Ma, X. (2009). Climate change impacts on crop yields, crop water productivity and food security – A review. *Progress in Natural Science, 19*, 1665–1674.
Parry, M. (1990). *Climate change and world agriculture*. London: Earthscan.
Rosenzweig, C., & Parry, M. (1996). Potential impacts of climate change on world food supply. *Nature, 367*, 133–138.
Troughton, M. (2004). Agriculture and rural resources. In B. Mitchell (Ed.), *Resource and environmental management in Canada: Addressing conflict and uncertainly* (3rd ed., pp. 233–264). Don Mills: Oxford University Press.
Wallace, I., & Brklacich, M. (2010). Agriculture and rural resources. In B. Mitchell (Ed.), *Resource and environmental management in Canada: Addressing conflict and uncertainty* (4th ed., pp. 274–297). Toronto: Oxford University Press.

Mike Brklacich is a Chancellor's Professor in Geography and Environmental Studies at Carleton University, Ottawa, Canada. He received his Phd in Geography from the University of Waterloo in 1989. His research focuses on the capacity of rural communities to adapt to environmental, social and economic change, food systems and security, and community engagement practices.

Maureen Woodrow is a sociologist who specializes in rural sustainable community development. Her research includes community level work in northern Alberta, Eastern Ontario, Northern Ontario and Newfoundland and Labrador as well as South America, Mexico and Wales. She holds a Ph.D. in Sociology from Laval University with a graduate degree from University of Louvain, Belgium, and an undergraduate degree from Memorial University.

Chapter 3
Analysis of Power Relations among Actors and Institutions in the Process of Agricultural Adaptation to Climate Change and Variability from the Diffusion of Innovations Perspective

Oumarou Daouda and Christopher R. Bryant

Abstract One component of adaptation to climate change is the promotion of innovations. Who says innovation, also talks about innovation adoption, and thus ultimately taking a decision. Decision making in relation to innovation adoption is a social process, because the decision maker often involves the participation of other members of society, including sometimes the members of his or her own family group. The elements of the social system that need to be taken into account in an innovation diffusion process are the norms that reflect the established patterns of behaviour for members of the social system. Recognized leadership in opinions is a major way in which a person can informally influence the attitudes of others so that they make changes in a desired direction. Such a change agent is thus someone who is able to influence the innovation decisions of others, including in a direction that the change agent endorses.

In Quebec, farm club advisors and suppliers (sellers of inputs and agricultural equipment) are among the major players in the agricultural sector in this respect. Beyond the services of support, advice and monitoring which are provided to farmers, these actors have also become hubs around a whole process of design and dissemination of innovative agricultural practices which can lead to successful adaptation to climate change. These stakeholders have favoured an approach centred on the "human" side of the equation; they have earned the trust of farmers

---

O. Daouda (✉)
Geography, Université de Montréal, Montréal, QC, Canada

United Nations Development Programme (UNDP), Africa
e-mail: omardaouda@gmail.com

C.R. Bryant
University of Montréal, Montréal, QC, Canada

School of Environmental Design and Rural Planning, University of Guelph, Guelph, ON, Canada
e-mail: christopher.robin.bryant@gmail.com

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_3

and assume a leading role in the design and dissemination of innovative practices to adapt to climate change and variability.

Based on focus group analyses and interviews with farmers and various agents of change, we show how the relationships among actors at the local level has created a fertile ground for the emergence of material and immaterial innovations that strengthens the resilience of the agricultural system, even if originally such innovations were not intended to fight against the effects of global warming.

Keywords Innovations • Diffusion • Adaptation • Agriculture • Climate change • Stakeholders • Social capital • Maladaptation

3.1 Introduction

Adaptation is a very broad concept that involves choices at different scales. It involves more than just a simple decision, because it can also involve the implementation of national policies. However, in the field of agriculture in relation to climate change and variability, the literature is dominated by studies on adaptation especially at the local level (Bryan 2009; Bryant et al. 2007; Burton 1998; Nelson et al. 2007; Reid 2004). Farmers use a wide range of adaptation options such as changing planting dates, choice of cultivars such as genetically modified organisms, improving their system of water management, tillage, or any aspect of their farm management system (Smith and Skinner 2002; Smithers 1997; Wall 2005). Furthermore, adaptation options in agriculture can be divided broadly into four categories according to scale and the actors involved (Smith and Skinner 2002). These are: (1) technological development; (2) government programs and insurance; (3) agricultural production practices; and (4) the farm's financial management. However, access to these types of adaptation is related to system vulnerability and the system's adaptation capacity.

According to IPCC (2001), vulnerability reflects the susceptibility of a system to cope with adverse effects of climate change and variability, including extreme events. Regarding agriculture, Reid et al. (2007) describe vulnerability (V) of an agricultural system as a function of exposure-sensitivity (E) to environmental changes (climate change) and adaptive capacity (A) of the system. This statement can be summarized with the following mathematical formula:

$$\mathrm{V(ist)} = f(\mathrm{Eist};\ \mathrm{Aist})$$

Where, V (ist) represents vulnerability of system (i) to climate stimulus (s), at time (t). Eist is exposure-sensitivity of system (i) to climate stimulus (s) at time (t), and Aist is adaptive capacity of system (i) to climate stimulus (s) at time (t).

A practical reading of this equation shows that the greater the exposure-sensitivity of a system, the greater its vulnerability, while greater adaptability results in reduced vulnerability (Smit and Pilifosova 2003). Exposure or sensitivity refers to the susceptibility of the system's alteration by climate stimuli. In agriculture, climatic stress should not be isolated from other sources of stress experienced also at the local level, as well at broader scales, in relation to changing economic, social, political and environmental conditions. As for adaptability, it refers to the potential of a system, community or region to adapt to the effects or impacts induced by climate change (Yohe and Tol 2001). In agriculture, this adaptability is assessed in several ways, depending on context, such as fluctuations in financial markets, the availability of technology, institutional support, changes in commodity prices or changes in social networks.

3.1.1 The Determinants of the Decision-Making Process

The perceived characteristics of an innovation (for example a new technology) relate to factors which encourage its adoption or diffusion. Rogers (1995) defined five such factors: the relative advantage, compatibility, observability, complexity and testability of the innovation. The characteristics of an innovation determine its degree of adoption. In this regard, several studies confirm this analysis (e.g. Bessant 2006; Brodt 2009; Pannell 2006). For example, Atwell (2009) uses the theory of the diffusion of innovations and the process of adaptation to climate change and variability to determine how rural stakeholders in the U.S. Corn Belt make decisions in an uncertain socio-economic and environmental context. It appears from this study that farm compatibility plays an essential role in the decision to adopt an innovation. Thus, the majority of farmers felt that their willingness to adopt permanent conservation practices is strongly influenced by the compatibility of these practices with their current farm. For example, many farmers reported that changes in agricultural equipment or difficulties in application of herbicides and pesticides were major characteristics involving exorbitant financial costs. Similarly, Pannell (2006) argues that Australian property owners are more likely to adopt innovations, when they are seen as superior to the practices they replace and when they are easy to test. Moreover, failure to adopt or a low level of adoption of a new practice is related to its inability to provide a relative advantage particularly in economic terms or because of difficulties encountered by property owners when the new practice was tested (Pannell 2006). However, if the characteristics of an innovation are not to be overlooked, it appears that the social system is the core element of the decision to adopt innovations, as well as a key determinant of adaptive capacity (Table 3.1). Ultimately, the decision to adapt to climate change and variability is related to the nature of the social system in which the individual resides.

The social system refers to social norms and the degree of interconnection of social networks. Indeed, decision-making in connection with adoption of an innovation is often a social process, as the decision maker often involves the participation of other members of society, or sometimes other members of a family group. According to Rogers (1995), members of a social system may be individuals, informal groups, or organizations. In the context of climate change and variability, adaptation decisions depend on many characteristics and the nature of the social

Table 3.1 Determinants of adaptive capacity

Key determinants	Description
Knowledge	Ability to accurately identify manifestations of the changes and their implications
Technology	Availability and access to technological options for adaptation
Resources	Availability of resources (financial capital, physical resources) for adaptation
Institutions	Structure of the basic institutions and power relations between them
Human capital	Education, skill, experience and individual's overall ability
Social capital	Informal social networks and collective community life that influence ability and willingness of communities and individuals to work together to achieve common goals
Risk management	System susceptibility to manage risks, including risk-sharing among stakeholders
Information management	Ability of decision makers to manage information including the process of information gathering and its evaluation
Farm succession	Presence of a new generation to take over and ensure continuity of business of an agricultural enterprise

Bryant et al. (2008), Smit and Pilifosova (2003), Yohe and Tol (2001), Déluska (2010)

system (Smith and Skinner 2002). Atwell (2009) also reported that social ties at the community level were mentioned by American corn producers as very important in their decision-making process regarding adaptation. These farmers stressed the importance of their neighbourhoods, their social networks and their rural communities in their decision making. For example, many farmers admitted being influenced by the practices and beliefs that characterize their neighborhoods. Social networks also play an important role in information transfer relating to agricultural practices, because they also facilitate the adoption of new ideas (Atwell 2009; Bryant et al. 2000, 2008; Croppenstedt 2003; Blennow and Persson 2009).

Simpson (2000) corroborates this analysis on the importance of social networks in the adoption and diffusion of innovations by emphasizing that changes in Malian agricultural production systems occured through technological changes which were part of clusters of innovation and which were influenced by both formal and informal communication systems. According to Simpson, while the two systems (formal and informal) have both made significant contributions, it appears that the ability of farmers to innovate and to absorb exogenous technologies to meet their individual needs was significantly more effective than the formal system of research and development. This performance derives from the ability of informal systems to propose viable technological options and responses adapted to farmers' specific conditions.

However, the formal social system represented by NGOs and extension services continues to play a leading role in the adoption and diffusion of innovations. Moreover, according to Sodiya et al. (2007), the accessibility of services offered to farmers by extension services greatly influences the degree of adoption of new agricultural technologies. Nevertheless, Goldberger (2008) nuances this reflection by highlighting the fact that the lack of post-training follow-up often results in the failure to consider farmers' knowledge received from NGOs.

Overall, agricultural innovation is a complex system covering both new technologies but also the institutional changes that some researchers term as being social innovations. This refers to any initiative or process that changes the basic routines, resources and authority flows or beliefs of any social system (Moore and Frances 2011). Therefore, innovation is regarded as the outcome of networking and interactive learning among multiple and heterogeneous groups of actors, involved in its process and diffusion (Klerkx et al. 2010; Spielman et al. 2009).

In this context, several studies have analyzed agricultural innovation systems in order to better understand the main drivers of socio-technical change in agriculture. Examples of this are many and varied. They range from analyses of how changes occur among farmers due to the actors involved in the process of adaptation and innovation (Atwell 2009), to the motivation behind forest owners' adaptation to climate change (Blennow and Persson 2009), or again to stress analysis of the adoption of fertilizers by farmers (Croppenstedt 2003).

In general, several research studies on this subject have suggested the significant role of networks in the innovation process. However, recognizing that transmission of information, ideas, practices or standards, is usually done via networks (Dale et al. 2010; Davis et al. 2007; Frank 1997) demands de facto that the various roles and functions of actors and institutions involved in the process of innovation be examined. In addition, it has been shown that not only do innovation networks contribute to changing agricultural practices, but they are also the cause of changes in the institutional context in which these practices occur (Buurma 2011; Hermans et al. 2012).

In order to explore the main areas of influence of the agricultural innovation system in the Monteregie-west region, located in southwestern Quebec, we formulated the following research question: what are the relations of power between actors and institutions contributing to the process of innovation? In other words, in these power tensions between stakeholders in agriculture in this region who influences whom and to what degree?

To pursue this, it is important to remember that the social network is a key element in the diffusion of innovations (Rogers 1962; Warriner and Moul 1989). Social networks refer to all groups of actors (individuals and organizations) which are involved with operators in support of agricultural production.

3.2 Study Area and Methodology

3.2.1 Study Area

The Monteregie-west region (Fig. 3.1) is endowed with a very suitable climate and land resource for agriculture. It accounted for about 9 % of Quebec's total farmland

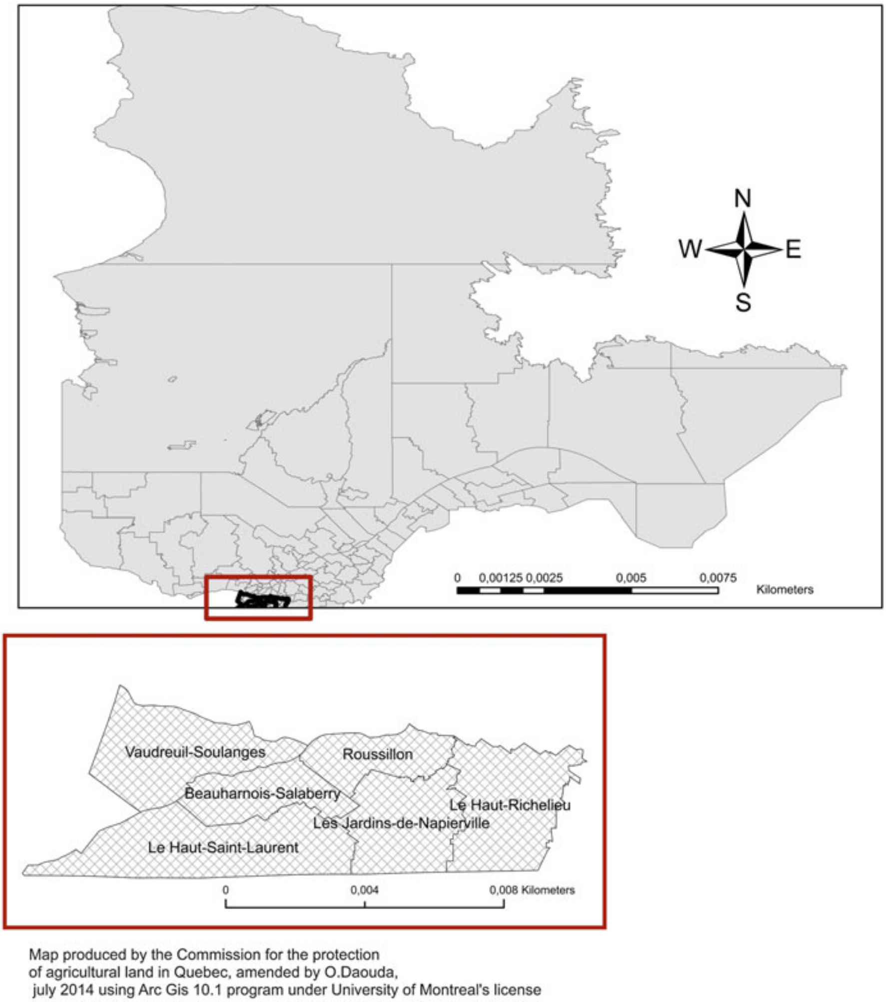


Fig. 3.1 Location of the regional municipal counties of Monteregie West in the context of Quebec

in 2011 (Statistique Canada 2011). For more than a decade there has been a growing decline in farm numbers estimated at 2740 farms in 2011, a decline of 9.3 % compared to 2001. For the same period, the number of farmers follows the same trend with a decrease of 42.5 % with an estimated number of 3716 farmers in 2011 (Statistique Canada 2012), obviously associated with an increasing farm size. The majority of farmers are owners of the farmland they operate, while land leased from the government and sharecropping is relatively unimportant. However, about 20 % of agricultural land is leased. Plant production (64 %) exceeds livestock (Table 3.2), probably stimulated by the rise in cereal prices.

Table 3.2 Monteregie West: distribution of agricultural holdings by production sector in 2011

Cattle	Pig	Poultry and egg production	Sheep and goats	Other animals	Grains and oil seeds	Vegetables and melons	Nuts and fruit	Greenhouse, nursery and floriculture	Other crops	Cattle and milk production	Cattle (including feed lot operations)
22 %	2 %	1 %	0 %	6 %	35 %	9 %	5 %	4 %	10 %	5 %	0 %

Statistique Canada (2012)

The majority of farms in this region belong to the higher gross farm income category. At the time of the last agricultural census (2011), 36 % of the farms in the region generated revenue exceeding $250,000 (Statistique Canada 2012).

The literature review (Bryant et al. 2007, 2008, 200) and contacts with stakeholders in the field (including during previous investigations in this region) highlighted problems facing Quebec agriculture in general. These problems are social (lack of young farmers), economic (e.g. urban sprawl on farmland, inappropriate agricultural policies, loss of crops, fluctuation in the price of agricultural products. . ..), and environmental (often caused by agricultural intensification that causes soil degradation, water pollution, amplified by the global warming phenomenon).

To tackle these challenges, responses can be organised in terms of the form of innovation, and whether they are primarily technological (such as agricultural mechanization, biotechnology) or social (restructuration of agricultural support organizations, the arrival of new actors). From this perspective, this study is justified by the overriding need to analyze innovation processes underway currently in Quebec's agricultural sector in the context of adaptation to climate change and variability, in order to inform and assist the government, as well as private investors and all stakeholders in agriculture in moving towards an efficient and sustainable climate transition.

3.2.2 Methodology

3.2.2.1 Participants Profile

Since farmers were the target audience for this study, we had to consider their busy schedule for interview planning. Nevertheless, using the snowball method (Bradshaw and Stratford 2000; Gumuchian and Marois 2000; Valentine 2005), we were able to reach 52 respondents including 32 farmers. A high proportion (i.e. 75 %) of famers who were interviewed had more than 20 years of experience in agriculture. The farm succession issue was raised several times during our interviews, which led us to include three young farmers among participants. Agriculture can be characterised by its level of sectoral diversification and any study pertaining to agriculture must consider this issue. In Monteregie-west, arable crops constitute the most dominant crops mainly corn and soya (Table 3.2). This distribution was taken into account in the selection of participants. However, we extended the sample beyond this distribution by meeting with other members of farmers' families in this area including steer and goat breeders, which are marginal agricultural producers in the area (Table 3.3).

Table 3.3 Respondents' profiles

Farmers			Other stakeholders
Production sector	Experience	%	Business sector
Arable crops 68 %	<9 ans	3	Agronomists
Dairy 3 %	10–19 ans	25	Marketing, advertising and promotion of agricultural products
Dairy and arable crops 21 %	20–29 ans	38	Agricultural machinery manufacturer
Vegetables 3 %	>30 ans	34	Distributor of organic and non-organic fertilizers
Others 6 %			Provider of agricultural genetic
			Insurance damage and financial service
			Transmission of knowledge service and networking in agriculture and agri-food

3.2.3 Data Collection

This study is concerned with the production of empirical knowledge related to the process of adoption and diffusion of innovations in agricultural production in Quebec, as adaptation strategies to climate change and variability. Grounded theory is the most appropriate methodology for this (Glaser and Strauss 1967). It is an inductive approach that generates three types of knowledge: theoretical, empirical and methodological (Quattrone 2000). Empirical data serve as the starting point for the development of a theory for a given phenomenon. The choice of this method stems from its ability to extract a theory from empirically observable phenomena (Yeung 1997).

3.2.3.1 Interviews

Primary data were collected through a series of interviews. Each interview lasted from 60 to 90 min. The individual interviews were recorded on audio tape. Some were later transcribed to complete the details that escaped the interviewer when taking notes. The interviews started off with some general information questions to determine the profile of the respondent. A second set of questions concerns measures implemented by the farmer to make his farm profitable. Subsequently, the respondent was invited to give his assessment of the global warming phenomenon, as well as strategies and measures to cope with it. Some questions prompted farmer to analyze the situation of their farm in relation to global warming phenomenon (see Appendix 1).

3.2.3.2 Theoretical Sampling

During the process of analyzing the interviews, it became evident that some actors had the potential to elucidate some important points for our analysis. In particular, it became evident that agronomists and suppliers are key actors in agriculture of the study area. In Grounded Theory, *theoretical sampling* is about collecting data from some actors to develop certain concepts that were already beginning to emerge after initial phase of codings and categorization. Theoretical sampling does not aim to get a sample of participants that is representative of the population, but to query respondents that can extend the understanding of a theory, a process or an emerging concept. It ceases as soon as the understanding of the process reaches saturation point, i.e. when no new element emerges from the interviews. Theoretical sampling was carried out first with agricultural input suppliers (of agricultural machinery, seeds, fertilizers, pesticides, herbicides). We also met with ten agronomists, 60 % of whom were from the private sector mainly seed distributing companies (such as Monsanto, Seresco. . .), agroenvironment clubs and cooperatives. Government was represented by the Ministry of Agriculture, Fisheries and Food of Québec (MAPAQ). We also met a representative of the Union des Producteurs Agricoles du Québec (UPA) (i.e. Quebec farmers union) (Table 3.3).

3.2.3.3 Data Analysis

The methodological approach is based on the grounded theory according to Strauss and Corbin (1990) and Chesler (1987). Data analysis took place in three main stages:

Step 1: We conducted an in vivo coding line per line of each interview. The text of each interview is read carefully, key phrases are underlined and rewritten in the right margin of the text.

Step 2: Key phrases are reduced and reformulated into codes consisting of short phrases that capture the main idea developed by the respondant; they are grouped. This step is repeated, because several structures of groupings are made and unwrapped, with the sentences constantly being moved between groups. This process is the fundamental element of the 'constant comparison method' (Glaser and Strauss 1967). Indeed, the consolidation of codes and their separations from each other required series of constant and continuous comparisons.

Step 3: Reduction of code groups and labelling. The process of constant comparison is mandatory at this stage too. It is often referred to as meta-coding (Charmaz 1983). The number of code groups is reduced using a method of continuous combining and comparing between different groups. The decision of placing entries between groups involves comparisons that are both implicit and explicit resulting in an increasing degree of interpretation. The end result of this step is

Table 3.4 Examples of grouping of phrases by code group

Pressing need to stay on the lookout for news
Being attentive to what is new
Grow and develop in seeking new technologies
Prefer inventions producing profit
Wanting to keep pace with the appearance of new varieties
Consulting specialized journals
Surfing on the internet
Persuasive role of agronomist in decision
Having considerable persuasive weight from farmer
Providing after sale custom advice to cope with competition
Selecting seed (hybrids) for farmer
Living in the uncertainty
Inaccuracy of weather forecasts
Climate normal overflow
Loosing control, climate-dependent
Acknowledgement of impotence
Uncertain future
Dealing with seasonal instabilities
Perceiving a changing climate
Seldom planning for long term because of inaccuracy
Uncertainty about market trends

the creation of a number of broad classes of codes or meta-groups, conceptually distinct and having a higher level of abstraction (Table 3.4).

3.3 Results: Discussion

3.3.1 Impacts on Social Capital

The data analysis resulted to the establishment of a main category called 'influence of private companies' (Table 3.5). The other categories include "Challenges and issues of contemporary agriculture", "Influence of private companies", "Dynamic decisions", "Network interaction", "New ways of thinking and doing". Also, considering the various divisions of this category, the study reveals firstly that social capital among farmers in the study area is low, and secondly that farmers are much more attracted by private companies with whom they have business partnerships based on mutual trust.

Weakness of social capital is the result of competition and lack of mutual trust between farmers, exacerbated by weak social ties. For example, a farmer claimed:

> If I have problems in fields, I appeal to suppliers or their representatives to find solutions. They are the ones who assist us, because they are those who have received information from

Table 3.5 Endorsement of the main category (N = 52)

Main category	Number of participants endorsing category
Influence of private companies	
Low social capital: ambivalent social relations the temptation of private companies	24
	48
	33
Business partnership based on mutual trust	27
The dynamics of diffusion process	

> the companies. I have more trust in the agricultural professional. Other than that I do not trust my neighbour, that's for sure. But on all sorts of other things, yes we will talk, we will exchange, but when it comes to income, you do not talk about it to your neighbor. [Henryville farmer]

In this regard, assuming that social capital is a key determinant of adaptative capacity (Bryant et al. 2008; Smit and Pilifosova 2003; Yohe and Tol 2001), it would appear to be appropriate to deduce that lack of social capital can be a serious handicap for a better resilience of agriculture to climatic and socio-economic changes. Actually this is not the case, as farmers as well as other stakeholders are confident about the resilience of agriculture, which is also supported by a recent government report (Agriculture and Agroalimentaire Canada 2013).

> One does not end by adapting, it is done continuously. Those who will produce at a lower cost will succeed, others will close. For example, we will adjust the types of production for livestock feeding. Also, crop types and tillage techniques will evolve. But for us, this is not so much due to climate change. It is more a progress in technologies and techniques. . . and ways of making it happen. [Sainte Martine farmer]

This paradoxical situation is explained by the fact that Canadian agriculture in general and Quebec agriculture in particular rely on innovation (technological and social) to adapt, given that access to information and therefore innovation is widely advocated as a coping strategy (Buurma 2011; OCDE 2013; Ramez 2013; Ribeiro 1988; Smith and Skinner 2002; Smithers 2001; Sumberg 2005). However, innovation, its design and its dissemination are social processes in the sense that no sociotechnical system operates independently, but is the result of activities carried out by human actors associated with social groups.

The literature on the strength of social ties can help us better understand the nature of the relationship between social actors and the effects of these links on their behaviour and information sharing activities. In his conception of the role of social networks, Granovetter (1973) highlights the fact that low interpersonal relationships, although they reflect a low level of trust between actors, can however facilitate the transfer of knowledge especially access to numerous and diverse informations (Rindfleisch and Moorman 2001), as they are necessary for the transfer of simple and explicit knowledge (Hansen 1999). Brown and Reingen (1987) complete this by stating that the absence of weak ties would probably hamper a wide diffusion of ideas. They justify this by showing that if the diffusion of innovations is done only through strong interpersonal relations between different social networks, it is likely that it is limited only to a circle of individuals. Weak interpersonal relationships therefore represent bridges between different social networks, so that they can play an important role in the dissemination of information.

Similarly, strong social ties appear to be the basis for a high level of mutual trust (Levin et al. 2004), which is useful for solving problems (Cross and Sproull 2004; Uzzi 1997), reduces resistance to change, and provides comfort in a context of uncertainty (Krackhardt 1992). In other words, anxious individuals exposed to risk are more likely to use strong ties to protect themselves and thus reduce uncertainty.

It follows from this reasoning that the diffusion of innovations in the context of global changes (such as climate change and variability), makes the viability and efficiency of the agricultural adaptation process dependent of the balance of the links between various actors involved in the process of adaptation. If CCV thus represents a complex and multidimensional issue (Bryant et al. 2000) and an additional threat to agriculture (OCDE 2009), it is surprising to note that adaptation of agriculture to CCV has considerably changed the functioning of various components of the social fabric of the region by changing the relationships between stakeholders at local level. Not only does adaptation requires farmers to establish solid and close partnerships with exogenous economic actors, but yet it also results in a societal upheaval, illustrated by the low social capital existing within the farming communities. Nevertheless, these weak links are useful to ensure better access to information, i.e. a wide diffusion of innovations.

3.3.2 Influence of Private Companies

Issues relating to adaptation of agriculture to climate change and variability also need to be approached at the macro level for a better understanding. From this perspective, it is clear that the innovation system responds primarily to market requirements (Sally 2011). An economic tendency leads to the private sector taking control of knowledge production and dissemination as well as information and technology (The World Bank 2006). This increases the role of the market in determining agricultural stakeholders' adaptation strategies to uncertainties including those related to climate (Sumberg 2005; World Bank 2006). This factor modifies the power balance in favour of those who already have access to technology and information, i.e. private companies. For example according to the UNCTAD Secretariat (2006), the agricultural biotechnology industry remains one of the most concentrated in the world, with the majority of the patents belonging to agrochemical giants. Similarly, Blay Palmer (2007) based on a case study of agricultural biotechnology in Canada, reports that publicly accessible varieties of soybean seed that stood at 90 % in 1975 has decreased considerably to stand at only 10 % of market share in 1998. The development of new varieties of soybeans has since fallen into the hands of private companies. This led to the development of genetically modified variety called "Roundup Ready soybean". Therefore, the new agreement governing the use of this variety of seed by farmers creates in fact a market-based seed industry controlled by private companies in so far as farmers are forced to buy seed each year from these companies (Blay Palmer 2007).

On another issue, Wiersinga et al. (2011) not only confirms the leading role played by the private sector in the development and dissemination of hybrid vegetable seeds of high quality for farmers in South-East Asia, but he also highlights the strategies implemented by companies to consolidate their dominant position among the plethora of stakeholders in agriculture in particular, through intense marketing campaigns, demonstrations and extension activities. At this level, the agronomist's role is important, because even though he usually represents the companies for which he works, he is the intermediary between stakeholders and as such, plays the role of "innovation drivers" as they like to be qualified.

These examples show the balance of power relation among stakeholders, which is too far in the direction of private companies according to some observers. However, even from an economic point of view this looks like a case of imperfect competition. Yet, it has to be recognized that on the ground, actors adapt to it very easily. Indeed from an innovation diffusion perspective, the process of adaptation of agriculture to climate change and variability is very similar to a confrontation of the thinking and approach between stakeholders involved in this process. In this regard, our results show that farmers and companies converge toward the same vision, i.e. a productive and competitive way of farming based on the optimization of production costs. This contrasts with MAPAQ's balanced approach which calls for a more resilient agricultural system, in particular a rational use of fertilizers to safeguard soil health.

> …Furthermore farmers and agronomists should have the same vision, because those agronomists who graduate from universities have a mentality of Greenpeace, it's green! Our production aspect, they see it on environment. Me, I'm in business! For me production is to make a difference between the optimum and maximum[1] which we try to validate. [Standbridge Station farmer]

As it is evident, the agricultural innovation market is a promising market to work in. Moreover, it is boosted by the potential arising from global responses to climate change on farming in terms of innovations in fertilizers, equipment, machinery, biotechnology… This promising perspective in terms of market is possibly the cause of companies' activities and justifies their dominant position at the expense of other stakeholders. Nevertheless, this development brings to the forefront the recurring question of sustainability: is it necessary to let the market take the lead in the process of agricultural adaptation to climate change as was the case for mitigation through 'clean' development mechanisms? Can one reconcile agricultural productivity and economic profitability on the one hand, with the requirements of ecological integrity and social development? What roles do governments have to

[1] Optimum means crop production to the best efficient level obtainable under specific conditions. whereas maximum means producing to the highest possible level.

play in regulating this emerging market of agricultural innovations that is so lucrative in the context of adaptation to climate change? What are the characteristics of the innovation process that contribute to sustainable innovations?

These are topics that can be the subject of future research. However, the question is not whether Canadian agriculture in general and Quebec in particular will adapt, but rather how will it adapt.

3.3.3 The Challenge of Integrating the Risk of Maladaptation

The results analysis suggest that the first challenge faced by Quebec agriculture in the near future concerns particularly the issue of soil quality arising from its excessive and inappropriate use, given the growing demand for agricultural products. Certainly, some stakeholders such as MAPAQ and various farmers have raised awareness on the consequences of excessive intensification of agriculture in Quebec, mainly with regard to soil health. Yet, by side-stepping private companies on this lucrative market of agricultural innovation, the government takes the risk of providing opportunities for social and environmental problems to occur in the near future. This is to say that in spite of the current legislation, in particular the agri-environmental fertilization plan, nitrogen levels which declined at one point are now increasing, driven by the increase in the prices of agricultural products.

In such circumstances, economic considerations often outweigh environmental concerns, in so far as the temptation of short-term profit remains dominant for the majority of farmers, especially in conventional agriculture. This illustrates the dilemma faced by farmers and supremacy of tactical choices for generating immediate profits in strategic decisions. While adoption and diffusion of innovation behaviour reflects a rational selection of farmers in response to changes in their physical, social, economic and technical environment, paradoxically this also poses the problem of their skill and their ability to appreciate the burden of a potential maladaptation resulting from their decisions.

To understand this risk of maladaptation in Monteregian farmers' behaviours, it is useful to refer to the works of Chamala et al. (1980) and Warner (1974) who postulated that research on innovations is based on scientific values that are mainly profit-oriented, often neglecting the socio-economic and environmental aspects of development and marketing of innovations. If logically one can challenge some parts of this assumption, in particular that relating to non-consideration of socio-economic aspects, the domination of productivist thought embodied by private companies is confirmed by our study. Similarly in relation to the lack of consideration of environmental aspects which results in an increased pressure on soil resources, at the risk of accelerating its depletion.

In addition, innovations development in Montegegie West is taking place without any formal framework for consultation between stakeholders. This 'confinement' of the development process of technological innovations has been highlighted by Saint and Coward (1977) and Goss (1979). Consequently, innovations that were originally intended to improve agricultural production by optimizing costs may have harmful effects on other components of agricultural system. For example in this case study, the socio-economic situation has promoted and facilitated the marketing of new equipment that is more powerful and versatile in order to overcome the lack of manpower, and that is also less energy-consuming in the context of the continued rise of oil prices. Unfortunately the impact of such equipment in terms of soil compaction has not been integrated in the design process. So, if Canadian agriculture has become actually efficient and competitive (Agriculture and Agri-Food Canada 2013), it also faces more pressing challenges such as soil depletion caused by compaction exacerbated by global warming.

> . . . when it rains it takes 1 or 2 days to recover. But if it rains and there is a day to recover, but it rains again, we cannot do anything. Then what we do, we move ahead with our work and we move into the recovery period to carry on with our work, and this is when we create compaction and growth comes to a santstill. [farmer Standbridge Station]

We believe that this situation is explained by the isolation that prevails within actors involved in innovation in terms of collaboration. Moreover, apart from the farmers to whom all other stakeholders converge, there is no real cooperation between actors in the development of innovations. This lack of co-operation is reflected on the ground by inconsistencies, the most noteworthy example of which is probably the withdrawal movement that can be observed in relation to crop insurance.

> The abandonment of crop insurance cannot absolutely lead to abandonment of my crops, because it is absolutely of no use. In production, insurance does not want to pay for field crops, unlike other productions, because there are many producers, and insurance has no real interest. [farmer Pike River]

Actually, considering the significant progress in scientific and technological innovations (such as biotechnology or agricultural equipment), more and more farmers in the study region feel they no longer want to participate in crop insurance. Among the reasons is their confidence in being able to harvest whatever the weather. This example illustrates a potential lack of synergy between La Financière agricole du Québec (in charge of crop insurance) on one hand and other stakeholders on the other, particularly suppliers of materials and agricultural inputs.

From another perspective, adoption behaviour in conventional agriculture does not stimulate farmers to consider potential externalities arising from agricultural innovations. Moreover, even if they are aware of the potential negative effects of their equipment or practices, it is difficult to do so without these technologies, at least in short term, with the risk of losing their competitiveness. The current conventional agriculture is dependent on the global economic system. In addition, cultural considerations such as production volume or yield per hectare are in the subconscious minds of the majority of farmers. These indicators remain the first signs of social and professional success. Nevertheless, there is an increasing awareness by certain farmers of the risks of possible unwanted side effects associated with an uncontrolled adaptation strategy. This increase in awareness is not accidental and it is primarily imposed by the combination of several factors. First on the agricultural level, as gradual degradation has reached alarming levels, any inaction would be suicidal. Then, socio-economic requirements characterized by the soaring prices of agricultural inputs and equipment, makes it imperative to look for other economic alternatives as means of production. Finally, the rise of citizen environmental consciousness represents a significant economic force that encourages operators to further integrate multifunctionality and ecosystem services in their agricultural production system. Indeed, changes in consumers choices and behaviour fits in a dynamic movement of preventive health, wellness and adoption of less impacting food choices for the planet, so that agricultural niche markets develop and consolidate, especially with regard to organic farming. In addition, conventional agriculture is also experiencing a timid return to secular practices such as tillage or croping on ridges, which were formerly agricultural production techniques with a high potential for soil conservation, but which however were marginalized because they became considered as inefficient.

If innovation adoption behaviour is a rational choice, then farmers' ability to integrate the risk of maladaptation in decision-making would lead to a better balance between physical, social and economic environments. In other words, considering risk of maladaptation by farmers involved in adopting innovations in harmony with their socio-economic and ecological environment could lead to a more effective and less damaging situation rather than choosing innovations based primarily on their perceived profitability. However, this would challenge the hegemony of private enterprises in the development and diffusion of innovations in Quebec's agricultural sector.

From this perspective it is interesting to note that farmers who integrate the danger of maladaptation into their decisions choose adoption behaviour that is contrary to the classical typology of adopters. In point of fact, this contradicts the relevance of adopters categories, particularly the word "laggard" defended by Rogers (1962, 1995, 2003), in reference to people who are the last to adopt an innovation according to profile categorization of adopters on the basis of their degree of adoption. Moreover, Frank (1997: 352) considers the term "insulting and derogatory to people who have made a rational and intelligent decision not to adopt".

3.4 Conclusion

It is clear from our research that technological innovations now form the backbone of the Quebec agricultural adaptation process in relation to climate change and variability. In the context of the complexity of the phenomenon of CCV and agriculture, actors' and institutions' mandates are constantly evolving and remain very dependent on how the evolution of socio-economic and environmental considerations are understood. It is in this framework and through using the grounded theory approach as the basis of the research methodology that this study examines the power relations between actors and institutions in the process of adaptation of agriculture to climate change and variability, based on a case study of the Montérégie West region of southwestern Quebec.

It appears from this study that the progressive shift toward technological innovations has led to a weakening of social capital among farmers. This is justified firstly because of competitive relationships between farmers, and also because of the influencial power exercised by private companies which are leading suppliers of materials and agricultural inputs. Social capital is one of the determinants of agricultural adaptability and its weakness could therefore be a handicap for Quebec's agricultural sector. However, literature on the dynamism of social links suggests that weak interpersonal relationships are useful in the context of the diffusion of innovations, as it promotes dissemination of information, while strong links that farmers have with private companies is justified by the fear of uncertainty and the desire to protect themselves and to cope with the consequences of global warming.

Despite this, however, the influence of private companies raises the issue of the sustainability of interventions sustainability in relation to the adaptation of Quebec agriculture to CCV. In this regard, the study reveals that two major factors pose potential risks that can cause maladaptation. First, the rule of economic considerations over environmental concerns, and the temptation of short-term profits often leads farmers to engage in practices that ultimately could be harmful such as the use of heavy equipment which can potentially degrade the soil. Moreover, preservation of soil health has become a major issue in Monteregie West. Second, focusing on the development of technological innovation can increase the likelihood of the risks of maladaptation, for example when technology development is undertaken in the absence of any framework for consultation between stakeholders both at local level or even higher levels (regional, national). Each party or stakeholder acts according to its own agenda which can result in failure to consider negative externalities that technological innovations could create for other components of the agricultural system.

Efforts should be undertaken for more meaningful involvement of all stakeholders in the adaptation process at the local level. In addition, it is essential to establish an inclusive framework for consultation of all stakeholders in agriculture in order to identify the challenges facing agriculture and the real needs in terms of adaptation. This could be undertaken at a higher level. However, participation of local stakeholders is required for such an approach to produce positive results for both the physical environment and socio-economic well-being of the agricultural sector in general.

Appendix 1

Section 1: Characteristics of the Farmer

Sex (to be completed by the interviewer)

(a) What is your age?
(b) What is your level of education?
(c) What does it feel to being a farmer today?
(d) What is the size of your farm?
(e) How long do you practice agriculture?
(f) What is the average annual income generated by your farming activities?
(g) Can you describe the types of contact you have in connection with your business?
(h) Do you have any professional contact with persons or institutions outside of your municipality? Please specify
(i) tell me about your sources of information regarding your activities? (type information, the source of information, the kind of content)
(j) What do you think of CCV? How do you rate it?
(k) Do you believe in this phenomenon?
(l) Do you think this is important to you?
(m) When did you become aware?

Section 2: Characteristics of Adaptation Options

(n) If you are aware, can you describe the steps you have taken to deal with it?
(o) In your opinion, apart from climatic factors, what are the major changes in agriculture over the past 20 years that have affected agriculture?
(p) Are there other factors that affect agriculture and you feel are of concern?
(q) What are the main benefits of the measures you have taken to adjust your farm? Give some examples?
(r) Tell me about the compatibility of these measures to adapt to the context in which you live? Which of these elements do you think is the most important to you? Explain why.
(s) Have you had to deal with any adaptation measure that you feel complex or difficult to understand or apply? Give examples.
(t) Despite this complexity, are you ready to adopt such an accommodation? If so, why?
(u) Have you experienced adaptation before final adoption? If yes, could you describe the process that led to the final adoption?
(v) Before adopting these adaptation measures, have you previously observed them elsewhere?

(w) Could you describe the main aspects of adaptation practices that have most influenced your decision (in order of importance)? (Relative advantage, compatibility, complexity, observability and testability).
(x) Describe me how you design your adaptation practices.
(y) What do you think of mitigation?

Section 3: The Communication Aspect of the Diffusion of Adaptation

(a) Tell me how you became aware of adaptation practices you have adopted.
(b) What are the other means of communication you use to get informed?
(c) Tell me about the types of information that are most useful for you to adapt? What are the contents? what are the sources?
(d) Which channels of communication was more persuasive to encourage you to adopt adaptation measures? Why?
(e) Are you or were you a member of a club board or any other organization? Which? Who are the other members? How do they work? What was your role?
(f) How do you describe your interaction with professionals in agriculture?
(g) Among all actors which has been (or is) the most useful to you in terms of adaptation to climate change? Why? How?
(h) Of all these players, which do you feel most like? What for? How?
(i) To what extent do you consider yourself as a farmer, different from others?

Section 4: The Temporal Aspect of the Diffusion of Adaptation Options

(a) Tell me about your decision to adopt adaptation measures? How did you come here?
(b) How long (day, month, years) have passed between the time you became aware of the threat for your farm and your decision to respond to these threats? Why this late/early reaction?
(c) What are the considerations or factors that were crucial in your decision?
(d) Do you regret your decision?
(e) What are the adaptation measures that you have taken first? What are the latest? Why?
(f) Have you adopted these adaptation measures after you have observed them in some of your fellow farmers? Either you are among the first to be adopted?
(g) Are you ready to adopt new and original adaptation measures, or would you rather wait for that other farmers experimenting before you adopt them?
(h) Are you ready to take risks to adapt your farm? Why?

(i) Have you made decisions regarding adaptation practices that you regretted later? Give some examples? Why this regret?
(j) Tell me how you do to minimize such risks?

Section 5: The Social System and Diffusion

(a) Have you consulted one or more farmers from the municipality or elsewhere to collect information or advice before deciding to adopt adaptation measures? Why this choice?
(b) Are you often consulted by colleagues on issues related to adaptation measures?
(c) Tell me about your relationship with your fellow farmers?
(d) Tell me about your dealings with your fellow farmers in the region and elsewhere?
(e) Have these exchanges helped you adapt your farm?
(f) What is your relationship with professionals in agriculture, UPA (union des producteurs agricoles), clubs, councils and other organizations?
(g) Who do you think has the most influence on you in terms of adaptation to climate change? why? Tell me how this influence?

Section 6: Conclusion of the Interview

(a) What do you think the role of young farmers in agricultural adaptation to CCV?
(b) Do you think the presence/absence of farm succession may influence your decision on adaptation? How?
(c) Tell me what is your view about the diffusion of innovations and agricultural adaptation to CCV?
(d) Is there anything else you want to add?

References

Agriculture Agroalimentaire Canada. (2013). Vue d’ensemble du système agricole et agroalimentaire canadien 2013. In Statistique Canada (Ed.).

Atwell, R. C. (2009). Linking resilience theory and diffusion of innovations. Theory to understand the potential for perennials in the US Corn Belt. *Ecology and Society*, *14*, (50):30. http://www.ecologyandsociety.org/vol14/iss1/art30/.

Bessant, K. C. (2006). A farm household conception of pluriactivity in Canadian agriculture: Motivation, diversification and livelihood *. (Essay). *The Canadian Review of Sociology and Anthropology*, *43*, 51.

Blay Palmer, A. (2007). Who is minding the store? Innovation strategy and agro-biotechnology research in Canada/Qui s'occupe du magasin? La strategie d'innovation et la recherche agrobiologique au Canada. *Canadian Journal of Regional Science, 30*, 39.

Blennow, K., & Persson, J. (2009). Climate change: Motivation for taking measure to adapt. *Global Environmental Change-Human & Policy Dimensions, 19*, 100–104.

Bradshaw, M., & Stratford, E. (2000). Qualitative research: Design and rigour. In D. Dragovich & A. Maude (Eds.), *Qualitative research methods in human geography*. Oxford: Oxford University Press.

Brodt, S. (2009). Factors affecting adoption of hedgerows and other biodiversity-enhancing features on farms in California, USA. *Agricultural System, 76*, 195–206.

Brown, J. J., & Reingen, P. H. (1987). Social ties and word-of-mouth referral behavior. *The Journal of Consumer Research, 14*, 350–362.

Bryan, E. (2009). Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environmental Science & Policy, 12*, 413–426.

Bryant, C. R., 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.

Bryant, C. R., Singh, B., & Thomassin, P. (2007). Vulnérabilité et adaptation aux changements climatiques au Québec au niveau de la ferme: leçons tirées de la gestion du risque et de l'adaptation à la variabilité climatique par les agriculteurs (p. 49). http://www.ouranos.ca/media/publication/149_Bryant1.pdf. Ouranos.

Bryant, C. R., Singh, B., & Thomassin, P. (2008). Evaluation of agricultural adaptation processes and adaptive capacity to climate change and variability: The co-construction of new adaptation planning tools with stakeholders and farming communities in the Saguenay-Lac-Saint-Jean and Montérégie Regions of Québec. Ottawa. Rapport de recherche pour projet A1332, soumis à la fin du mois de juin 2008 à Ressources naturels Canada, CCIAP 400.

Burton, R. J. F. (1998). The role of farmer self-identity in agricultural decision making in the Marston Vale community forest. (BL: DX211778). PQDT – UK & Ireland, n/a.

Buurma, J. (2011). Changing the crop protection or pesticide use regime in the Netherlands: An analysis of public debate. In S. Vellema (Ed.), *Transformation and sustainability in agriculture. Connecting practice with social theory*. Wageningen: Wageningen Academic Publishers.

Chamala, S., Van Den Ban, A. W., & Roling, N. (1980). A new look at adopter categories and an alternative proposal for target grouping of farming community. *Indian Journal of Extension Education, XVI*, 1–18.

Charmaz, K. (1983). The grounded theory method: An explication and interpretation. In Emerson (Ed.), *Contemporary field research*. Boston: Little Brown.

Chesler, M. A. (1987). Professionals'views of the "dangers" of self-help groups: Explicating a grounded theoretical approach. In *Center for research on social organization working paper series, d.o.S*. Ann Arbor: The University of Michigan.

Croppenstedt, A. (2003). Technology adoption in the presence of constraints: The case of fertilizer demand in Ethiopia. *Review of Development Economics, 7*, 58–70.

Cross, R., & Sproull, L. (2004). More than an answer: Information relationships for actionable knowledge. *Organization Science, 15*, 446–462.

Dale, A., Ling, C., & Newman, L. (2010). Community vitality: The role of community-level resilience adaptation and innovation in sustainable development. *Sustainability, 2*, 215–231.

Davis, K., Ekboir, J., Mekasha, W., Ochieng, C. M. O., Spielman, D. J., & Zerfu, E. (2007). Strengthening agricultural education and training in Sub-Saharan Africa from an innovation systems perspective case studies of ethiopia and mozambique. In: (IFPRI), I.F.P.R.I. (Ed.), 2033 K Street, NW Washington, DC 20006–1002 USA.

Déluska, K. (2010). Évaluation de la vulnérabilité des fermes productrices de maïs-grain du Québec aux variabilités et changements climatiques: les cas de la Montérégie-Ouest et du Lac-Saint-Jean-Est. Thèse de doctorat présentée à la faculté des études supérieures de l'universit de Montréal en vue de l'obtention du grade de PhD en géographie.

Frank, B. R. (1997). Adoption of Innovations in the North Queensland Beef Industry. III: Implications for extension management. *Agricultural System, 55*, 347–358.

Glaser, B., & Strauss, A. (1967). *The discovery of grounded theory*. Chicago: Aldine Publishing Co.

Goldberger, J. R. (2008). Diffusion and adoption of non-certified organic agriculture: A case study from Semi-Arid Makueni District, Kenya'. *Journal of Sustainable Agriculture, 32*(4), 531–564.

Goss, K. F. (1979). Consequences of diffusion of innovations. *Rural Sociology, 44*, 754–772.

Granovetter, M. S. (1973). The strength of weak ties. *American Journal of Sociology, 78*, 1360–1380.

Gumuchian, H., & Marois, C. (2000). Initiation à la recherche en géogrphie. Aménagement, développement territorial, environnement. In Montréal, L.p.d.l.u.d (Ed.).

Hansen, M. T. (1999). The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. *Administrative Science Quarterly, 44*, 82–111.

Hermans, F., Stuiver, M., Beers, P. J., & Kok, K. (2012). The distribution of roles and functions for upscaling and outscaling innovations in agricultural innovation systems. *Agricultural Systems, 115*, 117–128.

IPCC. (2001). *Summary for policymakers. Climate change 2001: Impacts, adaptation, and vulnerability, a report of working group II of the IPCC*. Geneva: IPCC.

Klerkx, L., Arrts, N., & Leeuwis, C. (2010). Adaptive management in agricultural innovation systems: The interactions between innovations networks and their environment. *Agricultural Systems, 103*, 390–400.

Krackhardt, D. (1992). The strength of strong ties the importance of philos in organizations. In N. Nohria & R. Eccles (Eds.), *Networks and organizations: Structure, form and action*. Boston: Harvard Business School Press.

Levin, D. Z., Cross, R., & Abrams, L. C. (2004). The strength of weak ties you can trust: The mediating role of trust in effective knowledge transfer. *Management Science, 50*, 1477–1490.

Moore, M.-L. W., & Frances. (2011). Surmountable chasms: Networks and social innovation for resilient systems. *Ecology and Society, 16*, 5.

Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources, 32*, 395–419.

OCDE. (2009). Integrating climate change adaptation into development cooperation: Policy guidance. OCDE. http://www.oecd.org/editions/corrigenda

OCDE. (2013). Les systémes d'innovation agricole: Cadre pour l'analyse du rôle des pouvoirs publics. In OCDE (Ed.)

Pannell, D. J. (2006). Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture, 46*, 1407–1424.

Quattrone, P. (2000). Constructivism and accounting research: Towards a trans-disciplinary perspective. *Accounting, Auditing & Accountability Journal, 13*, 130–155.

Ramez, N. (2013). How innovation could save the planet: Ideas may be our greatest natural resource. *The Futurist, 4*, 24.

Reid, S. (2004). Farm-level perception of and adaptation to climate risk in Perth County, Ontario. ProQuest Dissertations and Theses, n/a.

Reid, S., Smit, B., Caldwell, W., & Belliveau, S. (2007). Vulnerability and adaptation to climate risks in Ontario agriculture. *Mitigation and Adaptation Strategies for Global Change, 12*, 609–637.

Ribeiro, A. R. (1988). *Agriculture et progrès techniques: Études de la dynamique des innovations* (pp. 3–26). Cahiers du Brésil Contemporain. EHESS, Paris.

Rindfleisch, A., & Moorman, C. (2001). The acquisition and utilization of information in new product ailiances: A strerjgtii-of-ties perspective. *Journal of Marketing, 65*, 1–18.

Rogers, E. (1962). *Diffusion of innovations*. New York: The Free Press.

Rogers, E. (1995). *Diffusion of innovations* (4th ed.). New York: The Free Press.

Rogers, E. (2003). In Press, F. (Ed.), *Diffusion of innovations* (5th ed.). New York: Free Press.
Saint, W., & Coward, E. J. (1977). Agriculture and behavioural science: Emerging orientations. *Science, 197*, 733–737.
Sally, B. (2011). Shaping agricultural innovation systems responsive to food insecurity and climate change. *Natural Resources Forum, 35*, 185–200.
Simpson, B. M. (2000). Adoption et adaptation de techniques agricoles innovantes dans le sud-ouest du Mali [Adoption and adaptation of innovative farming techniques in South-West Mali]. Autrepart (La Tour d'Aigues), no, 5–27.
Smit, B., & Pilifosova, O. (2003). From adaptation to adaptive capacity and vulnerability reduction. In S. S. J. Huq & R. T. J. Klein (Eds.), *Enhancing the capacity of developing countries to adapt to climate change*. London: Imperial College Press.
Smith, B., & Skinner, M. W. (2002). Adaptations options in agriculture to climate change: A typology. *Mitigation and Adaptation Strategies for Global Change, 7*, 85–114.
Smithers, J. (1997). Human adaptation to climatic variability and change. *Global Environmental Change-Human and Policy Dimensions, 7*(2), 129–146 7, 129-human.
Smithers, J. (2001). Technology innovation as a strategy for climate adaptation in agriculture. *Applied Geography, 21*, 175–197.
Sodiya, C. I., Lawal-adebowale, O. A., & Fabusoro, E. (2007). Effect of private and public extension services on adoption of promoted cassava-based technologies in Ogun State, Nigeria. *Journal of Agricultural & Food Information, 8*, 35–47.
Spielman, D. J., Ekboir, J., & Davis, K. (2009). The art and science of innovation systems inquiry: Application to Sub-Saharan African agriculture. *Technology in Society, 31*, 399–405.
Statistique Canada. (2011). Recensement de l'agriculture 2011.
StatistiqueCanada. (2012). Recensement de l'agriculture 2011. http://www29.statcan.gc.ca/ceag-web/fra/transpose-var-transposer?geoId=241300000&selectedVarIds=3%2C2%2C10%2C1%2C7%2C6%2C5%2C4%2C9%2C8%2C28%2C12%2C, consulté le 23 octobre 2012.
Strauss, A., & Corbin, J. (1990). *Basics of qualitative research*. Newbury Park: Sage.
Sumberg, J. (2005). Systems of innovation theory and the changing architecture of agricultural research in Africa. *Food Policy, 30*, 21–41.
UNCTAD Secretariat. (2006). *Tracking the trend towards market concentration: The case of agricultural input industry, United Nations Conference on Trade and Development*. Geneva: UNCTAD secretariat.
Uzzi, B. (1997). Social structure and competition in interfirm networks: The paradox of embeddedness. *Administrative Science Quarterly, 42*, 35–67.
Valentine, G. (2005). Tell me about...: Using interviews as a research methodology. In R. Flowerdew & D. Martin (Eds.), *Methodology in human geograpgy: A guide for students doing a research project* (2nd ed.). Harlow: Pearson Education Limited.
Wall, E. (2005). Climate change adaptation in light of sustainable agriculture. *Journal of Sustainable Agriculture, 27*(1), 113–123 27, 113–123.
Warner, K. E. (1974). The need for some innovative concepts of innovation: An examination of research on the diffusion of innovations. *Policy Science, 5*, 433–451.
Warriner, G. K., & Moul, G. M. (1989). *Social structure and the choice of cropping technology, influence of personal networks on the decision to adopt conservation tillage*. Ontario: Department of sociology, University of Waterloo.
Wiersinga, R. C., Eaton, D., & Danse, M. (2011). Seed provision in developing economies: Converting business models. In S. Vellema (Ed.), *Transformation and sustainability in agriculture. Connecting practice with social theory* (pp. 131–146). Wageningen: Wageningen Academic Publishers.
World Bank. (2006). *Enhancing agricultural innovation: How to go beyond the strengthening of research systems*. Washington, DC: World Bank.
Yeung, H. W. (1997). Critical realism and realist research in human geography: A method or a philosophy in search of a method? *Progress in Human Geography, 21*, 51–77.

Yohe, G., & Tol, R. S. J. (2001). Indicators for social and economic coping capacity – Moving toward a working definition of adaptive capacity. *Global Environmental Change, 12*, 25–40.

Oumarou Daouda holds a PhD from the Université de Montréal (2014). The topic of his doctoral research was based on the model of diffusion of innovations as strategies of agricultural adaptation to climate change. Dr Daouda is also interested in issues related to environmental assessment and sustainable development. As a professional, Dr Daouda has an outstanding knowledge in the field of Environment, Natural resources, Rural Development and Climate Change with several years of experience as consultant/program analyst in international development in many countries.

Christopher R. Bryant received his doctorate in 1970 at the London School of Economics and Political Science (LSE), London. He was progressively Assistant, Associate and Full Professor in Geography at the University of Waterloo (1970 à 1990), then Full Professor in Geography the University of Montréal (1990 à 2014), and is now Adjunct Professor in Geography at the University of Montréal and also in the School of Environmental Design and Rural Planning, University of Guelph. He is one of the international leaders in research on urban/periurban agricultures (Canada, Western Europe and elsewhere), and he is also a recognized leader in the domain of adaptation of human activities (and especially agriculture) to climate change and variability, in local and community development, and in the strategic planning for local and regional development for and by citizens.

Chapter 4
Climate Change and Corn Productivity in West Montérégie, Quebec: From Impacts Anticipation to Some Adaptation Potentialities

Kénel Délusca and Christopher R. Bryant

Abstract The decision-making environment of farmers in Quebec is very complex as in most agricultural territories. In their decision-making process, farmers must deal not only with a set of socio-economic factors at different spatial and temporal scales, but also with biophysical elements likely to have a significant influence on the level of agricultural productivity. Among these, climatic conditions are fundamental to the development, growth and yield of crops. In a context of climate change and variability mainly characterized by rising temperatures and more frequent extreme events, climate conditions will become increasingly important in any process of informed decision-making on the farm.

From this perspective, the objective of this paper is twofold: (1) to present the potential impacts of climate change on corn yields for two municipalities in the West Monte´re´gie region of the province of Quebec; and (2) in the light of analyses carried out on some phenological stages of corn, to focus on some adaptation options likely to reduce the impact of anticipated climate conditions on corn yields in both municipalities.

To achieve these objectives, a methodological approach is adopted that combines five climate scenarios from the Canadian Regional Climate Model for the 2010–2039 horizon with the CERES-Maize crop model embedded in DSSAT.

Compared to the 1961–1990 reference period and considering the cultivars currently used, the impacts of climate change vary from one municipality to another. Within the municipalities, they depend on the climate scenario considered

K. Délusca (✉)
Institut des Technologies et des Études Avancées d'Haïti (ISTEAH), Port-au-Prince, Cap-Haïtien, Hinche, Haiti
e-mail: kenel.delusca@gmail.com

C.R. Bryant
University of Montréal, Montréal, QC, Canada

School of Environmental Design and Rural Planning, University of Guelph, Guelph, ON, Canada
e-mail: christopher.robin.bryant@gmail.com

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_4

and the fertilizing effect of carbon dioxide. However, in general terms, with the current cultivars, a yield decrease mainly due to an acceleration of the physiological maturity process has been anticipated for the future period under investigation.

By considering some cultivars that are better adapted to the anticipated climatic conditions for the 2010–2039 period, corn yields are projected to increase for most climate scenarios in the two municipalities. If the modelling exercise of climate change impacts on corn yields has provided useful insights into the technical adjustments to be made in order to reduce the negative impacts of climate change on crop productivity in the West Monte´re´gie region, it is nonetheless important to keep in mind that their adoption is not straightforward and is strongly linked to other types of stressors.

Keywords Climate change • Corn yield • Climate scenario • Crop modelling • Adaptation

4.1 Introduction

According to a majority of experts in the field of atmospheric sciences, anthropogenic climate change is part of the main challenges that current and future societies have had and will have to face during the coming decades (Wood 2008; IPCC 2001, 2007; Myhre et al. 2013). In support of the main conclusions of Working Group I of the Intergovernmental Panel on Climate Change (IPCC) on the scientific basis of climate change, Villeneuve and Richard (Villeneuve and Richard 2007, p. 11) argued: "The question is not about if the climate is changing, but how fast it is and will be changing". The detection of a trend in global warming and its attribution to human activities, notably an exceptional use of fossil fuels, an unprecedented level of deforestation and change in land use, were presented with greater certainty in the last two IPCC reports (IPCC 2007, 2013). According to these reports, expectations include, among other things, an increase in global average temperature of 4.5 °C by the year 2100, a change in rainfall regime, a rise in sea level, and also a modification of the variability of these parameters, including a change in the frequency of extreme events. These anticipated modifications of the global climate system are likely to affect most human and natural systems, particularly those with a strong reliance on climate conditions (IPCC 2001, 2007). Among these, the agriculture sector, strategic to the socio-economic stability of many countries, is often cited as a perfect example of a sector whose performance or state is strongly dependent on climatic conditions (Parry et al. 1999).

A severe drought in Australia during the years 2002–2003 significantly affected the agricultural production of this country and caused requests for assistance from almost half of the farmers (Bruce et al. 2006). In the Canadian Prairies, the major drought of 2002 had catastrophic consequences on the agricultural production of this region. In Quebec, during the cold and humid cropping season of 2000, crop yields significantly decreased and insurance claims considerably increased. Indeed, at the end of the growing season of 2000, corn yields were exceptionally low (between 2 and 6 t/ha, depending on the region) and allowances paid by the crop insurance program of the province for this crop reached the record level of $94 million (Financière agricole du Québec 2000). These examples illustrate very well the degree of dependence and the close link between agricultural production, including crop yields, and climate conditions. Any modifications of the global climate system, as projected by different Global Circulation Models (GCMs), will result in changes in global agricultural production, including changes in agricultural yields as well as agricultural land use and acreage. Maintaining a sustainable agricultural production level likely to satisfy the food needs of the world population is essential for the political, economic and social stability of present and future generations.

Given the importance of the agriculture sector and its degree of dependence on climate conditions, it is very relevant to appreciate the potential impacts of the anticipated climate change on crop yields. From this perspective, the objective of this article is twofold: (1) to present the potential impacts of climate change on corn yields for two municipalities in the West Montérégie region; and (2) to identify, in the light of analyses carried out on some of the phenological stages of corn, some adaptation options that could reduce the potential impacts of this unprecedented phenomenon on corn productivity.

This chapter is divided into three main sections. The first section describes the methodology adopted for this study. The two study areas and the key data used are presented, together with a description of the biophysical model used for the yields simulation process, and the explanations of the steps performed during the calibration and validation processes of the crop model. The second part presents the results and discussions. Finally, some conclusions and recommendations related to the assessment of climate change impacts on crop yields using dynamic model are formulated.

4.2 Methodology

Broadly speaking, the methodological approach adopted consists of a coupling of climate scenarios with a dynamic crop model for two time horizons, notably a reference period (1961–1990) and a future period (2010–2039). More specifically, using the dynamic crop model, corn yields are simulated for both time horizons, and the yield series are then compared in order to assess the direction and magnitude of climate change impacts on future corn productivity. Subsequently, an evaluation of the influence of some technical adjustments on corn productivity in the context of relatively warmer climate conditions was carried out. After a concise presentation of the study sites, the data used as well as the methodological steps undertaken are now presented.

Fig. 4.1 Administrative map of West Montérégie Region, including the case studies

4.2.1 Study Sites

Located at the southern part of Quebec and more specifically between 44 and 46° North latitude and between 72 and 76° West longitude, the West Montérégie agricultural region has an estimated area of 4651 km^2. It consists of six Regional County Municipalities (RCM) comprising 97 municipalities. The two municipalities under investigation, namely Sainte-Martine and Saint-Sébastien belong to the RCM of Beauharnois-Salaberry and Haut-Richelieu, respectively (Fig. 4.1). Agriculture is an important economic sector for the region. The crop production systems in the region, characterized by an increase in corn acreage, are favored by relatively mild climate conditions and the quality of its soil types (MAPAQ 2006). The climate of the region is among the hottest in Quebec (Morissette 1972). Generally, the soils have good agricultural potential (Morissette 1972; MAPAQ 2006). However, these soils sometimes have to contend with poor drainage that can jeopardize the realization of some agricultural operations, including land preparation and planting activities (Morissette 1972).

4.2.2 Data

Three main categories of data have been used in the process of assessing the impacts of climate change on corn yield for the West Montérégie region. These are observed climate data and climate scenarios, soil information and crop management practices described below, and observed data sets of corn yields. These yield data were used during the model calibration and validation processes. With respect to climate data, two sets of data were considered. The observed climate data were used only during the calibration and validation processes of the crop model.

Table 4.1 General information about the five climate scenarios produced using the CRCM

Climate scenario	CRCM version	GCM	Member	Domain
Hot and dry	4.2.0	CGCM3.1, version 2	#4	North America
Hot and humid	4.1.1	CGCM3.1, version 2	#5	Quebec
Cold and dry	4.2.3	ECHAM5 EH5_OM_20C	#1	Quebec
Cold and humid	4.2.3	ECHAM5 EH5_OM_20C	#1	North America
Median	4.2.3	CGCM3.1, version 2	#5	North America

Table 4.2 Soil information by municipality

Municipality	Representative soil type	Classification du sol
Ste-Martine	Clay	Orthic gleysol
St-Sébastien	Clay	Humid orthic gleysol

However, for the simulation process of corn yields during both time horizons, the climate outputs of the Canadian Regional Climate Model (CRCM) were used. The main features of this regional climate model are described in Music and Caya (2007), Plummer et al. (2006), and Caya and Laprise (1999). For the purpose of this study, five climate scenarios were developed by the Climate Scenarios Group of the Ouranos Consortium in Quebec and designated as follows: hot and dry; hot and humid; median; cold and dry; and cold and humid. These five climate scenarios have been developed using different domains and versions of the CRCM that has been forced by the A2 GHG emission scenario and driven by two GCMs, notably GCCM and ECHAM. For each of the previously mentioned climate scenarios, Table 4.1 provides details about the version of CRCM used, the GCM that has driven it, the simulation member and the domains that have been considered. Regardless of the time series considered, the following climate variables were used: minimum and maximum temperature, rainfall, and solar radiation. Unlike the two other variables, the solar radiation data used in the calibration and validation processes of the crop model were estimated using the method described in Bristow and Campbell (1984) and adapted by Savoie (2006).

The soil data required by DSSAT were taken from the digital soil database of the Research and Development Institute for Agri-Environment (IRDA 2007), and the Soil Landscapes of Agriculture Canada. For each of the two municipalities, the characteristics of the most common soil types in the vicinity of the location of the climate stations were used as soil information in DSSAT. For the layers available in these databases, these soil characteristics were mainly the texture, pH, organic carbon content, and cation exchange capacity. The total nitrogen by layer was estimated using a C: N ratio of 10:1. Table 4.2 provides some information on the representative soils type in each municipality. The pH of the surface layers of these soil types is generally acid; and their pH value is between 5.8 and 6.7 for Sainte-Martine and Saint-Sébastien, respectively. The organic carbon content of the surface horizons of these soils does not generally exceed 3.8 %.

4.2.3 Description of Corn Yield Simulations with DSSAT

DSSAT consists of a set of crop models that share the same input and output data formats (Hoogenboom et al. 1995; Jones et al. 2003). Version 4.0.2 was used in the different simulations presented in this study. DSSAT is essentially an interface that allows the user to manage and manipulate data related to environmental conditions, crop management practices and to perform and analyze results of different types of crop yield simulations. The crop model used for the simulations was the CERES-Maize model. By taking into account the dynamic between climate conditions, soil, nutrients and plant characteristics, different crop models available in DSSAT simulate, at a daily time step, the development, growth, and yield of different cultivars (Jones et al. 1990). A detailed description of the CERES-Maize model can be found in Ritchie et al. (1998).

In this study, a "water-limited corn yield simulation" was performed (van Ittersum et al. 2003). The choice of this crop yield type was essentially based on the assumption that the farmers of the municipalities under investigation controlled in an efficient way the diseases, insects, pests, weeds and nutrients content of their corn cropping system. Simply put, it was considered that these elements were not the main factors limiting corn productivity in these municipalities. Given the influence of atmospheric concentration in CO_2 on water use and biomass production (Tsuji et al. 1998), different atmospheric concentrations of carbon dioxide have been considered in order to quantitatively assess their influence on corn yield. This assessment was performed by comparing the yields with the atmospheric CO_2 concentrations of the reference period and the projected one for the A2 GHG emission scenario at the 2010–2039 horizon. The atmospheric CO_2 concentration for the reference period was estimated at 344 ppm, while that of the A2 GHG emission scenario for the 2010–2039 period was anticipated at 429 ppm.

4.2.4 Crop Model Calibration and Validation

Within the CERES-Maize model, the genetic characteristics of the cultivar are defined with some values for the genetic coefficients. These coefficients represent the responses of a given cultivar to environmental factors and determine also their yield levels (Hunt et al. 1993). These genetic factors are conventionally obtained through the establishment and monitoring of experimental plots or growth chamber experiments. Thus, genetic factors for some cultivars that have been calibrated under different environmental conditions are available in the CERES-Maize model. However, these calibrated cultivars in CERES-Maize are very rare for the specific conditions of corn production in Quebec. For the purposes of assessing the impacts of climate change on corn yields, any attempt to use these cultivars in Quebec

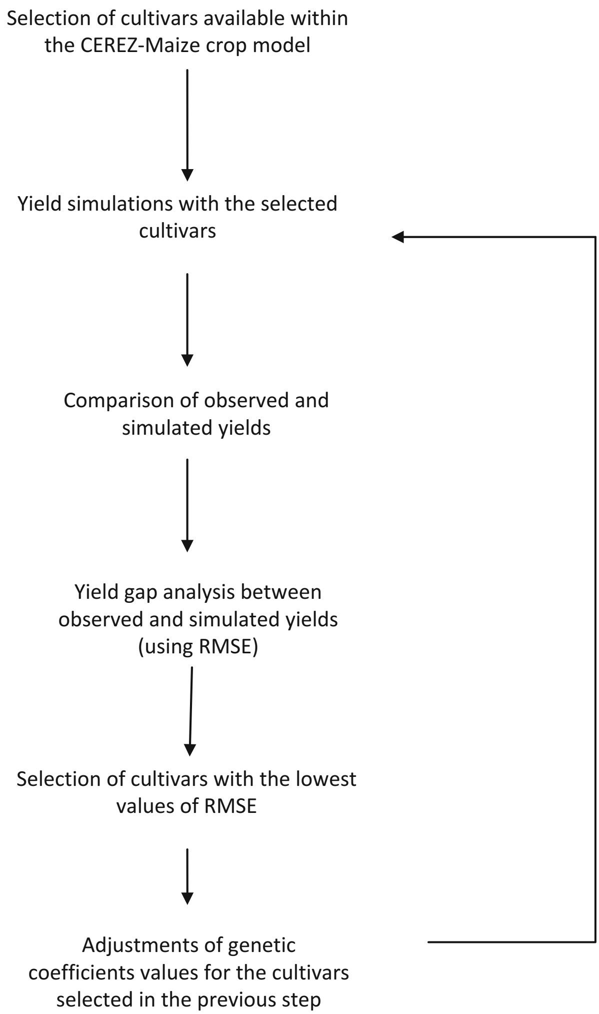


Fig. 4.2 Different steps of the crop model calibration process

without prior calibration and validation is incorrect unless one is performing a sensitivity analysis of corn yield to these cultivars. Therefore, a calibration process (Fig. 4.2) of different cultivars used in both municipalities during the reference period was carried out. It started with the selection of cultivars available within the model. This choice can be greatly facilitated by the knowledge of the user about the relationships between specific climate conditions and some phenological stages of the crop. Simulations are then performed for the selected cultivars. The yields member of data used simulated with these different cultivars are compared to the series of yields observed within the municipalities under investigation. The main goal of this comparison was to identify cultivars whose differences between the observed and simulated yields were the lowest. The Root Mean Square Error

(RMSE) was considered in the evaluation of the differences between the simulated and observed series. It was calculated using the following formula:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}}$$

P_i: simulated yields
O_i: observed yields
n: number of data used

Cultivars with the lowest RMSE values are kept for further steps of the calibration process. At this point, in order to keep lowering the values of the RMSE, some modifications had to be made to the genetic coefficient values of the cultivars selected in the previous step (assuming that management practices integrated into the crop model are reliable). First, we started by modifying the genetic coefficient values related to phenological stages of the crop, and second those related to yield components. Each series of changes made to the genetic coefficients of the cultivars is followed by some simulations steps, and a comparison of observed and simulated series using the RMSE. The process continues until the value of RMSE can no longer be decreased. The impossibility of reducing the differences between observed and simulated yields is often due to the fact that factors other than soil moisture also determine the observed yields levels. In other words, it may be practically impossible to reduce the gap for these years when the observed yields are mainly determined by other factors, such as diseases, insects, weeds, and the introduction of new technologies not considered by the crop model.

Studies that aim at assessing climate change impacts on corn yields involve, among other things, yield simulations for future periods. Before undertaking these simulations for the future, it is strongly recommended to ensure that the model is able to reproduce the observed yields both in terms of average yields and variability of yields (Martre et al. 2014). Based on this, the CERES-Maize crop model has been validated for the biophysical conditions specific to both municipalities under investigation.

The validation process consists of a comparison between the observed yields and those simulated using the historic climate data. Figure 4.3 describes the steps followed during the validation process. Two main parameters were considered in order to assess the accuracy or precision of the CERES-Maize crop model under Quebec's biophysical conditions. These parameters were the "d" and "RD" that have been evaluated using the following formulas:

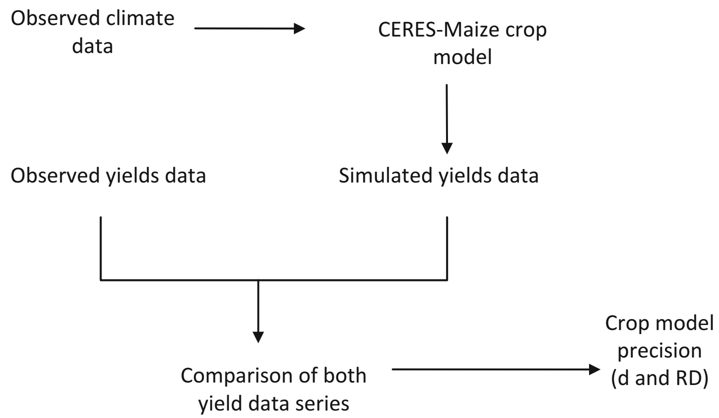


Fig. 4.3 Steps carried out during the crop model validation process

$$d = 1 - \left[\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} \left(\left|P_i'\right| + \left|O_i'\right| \right)^2} \right], 0 \leq d \leq 1$$

d: model accuracy or precision (unitless)
P'_i: P_i-O_{im}
O'_i: O_i-O_{im}
P_i and O_i: already defined
O_{im}: average simulated yields

$$\mathbf{RD} = \left[\sum \left(\mathbf{O_i} - \mathbf{P_i} \right) / \mathbf{O_i} \right) * \mathbf{100} \Big] / \mathbf{n}$$

RD: relative difference (%)
P_i and O_i: already defined

The "d" parameter, similar to the coefficient of determination R^2, directly compares model simulations with the observed data. A value of 0 for "d" means that the model is no better than a simple average, a value close or equal to 1 indicates a good model (Vanclay and Skovsgaard 1997; Mayer and Butler 1993; Fay et al. 2006; Anothai et al. 2008). RD, expressed in %, informs us on the difference between the average values of the observed yields with those that have been simulated by the crop model. According to Ritchie et al. (1998), an RD value of ± 15 % is fairly acceptable.

The impacts of climate change on corn water-limited yields have been undertaken using two main steps (Fig. 4.3). First, using different climate scenarios and different levels of atmospheric CO_2 concentration, a relative change in crop yields was evaluated for the reference cultivars. Then, an evaluation of the relative change in crop yields for some improved cultivars was also made. In the context of this chapter, an improved cultivar refers to a cultivar with higher yield potential under the anticipated climate conditions than that of the reference cultivar. Their choice was mainly guided by their genetic potential likely to allow them to benefit from the anticipated climate conditions under the different climate scenarios previously mentioned. In order to estimate the relative yield changes using both reference and improved cultivars, the following formula was used:

$$\textbf{Average yield change}\ (\%) = [(\mathbf{Y_f} - \mathbf{Y_r})/\mathbf{Y_r}]*\mathbf{100}$$

Y_f: average yield for the future period (kg ha^{-1})
Y_r: average yield for the reference period (kg ha^{-1})

4.3 Results and Discussions

The CERES-Maize crop model performed reasonably well in both municipalities. The values of “d” are greater than 0 and those of “RD” are within the acceptable range of $\pm 15\,\%$. For the municipality of Sainte-Martine, the values of “d” and “RD” were 0.52 and 14, respectively, while they were 0.36 and 14.7 for the municipality of Saint- Sébastien. The differences observed between the simulated and observed yields (Figs. 4.4 and 4.5) can be explained by several factors. These can be grouped into four broad categories:

1. The Model’s structure for some biophysical processes: The CERES-Maize crop model seems to be not too sensitive to the occurrence of early frosts. For some years, no major influence of a killing frost on corn yield levels was noted. For

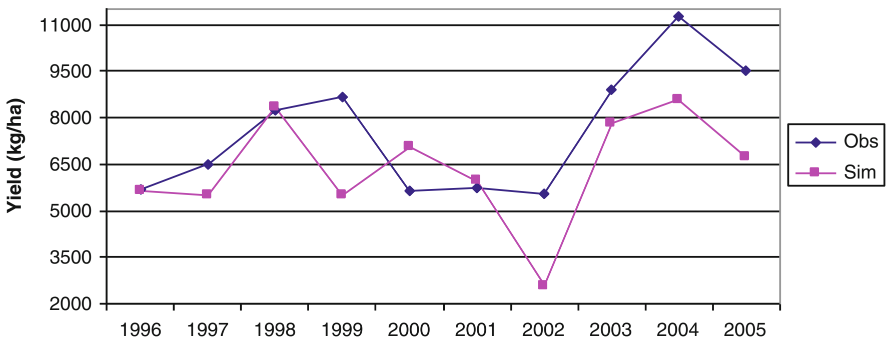


Fig. 4.4 Graphical representation of the results of the crop validation process for the municipality of Sainte-Martine

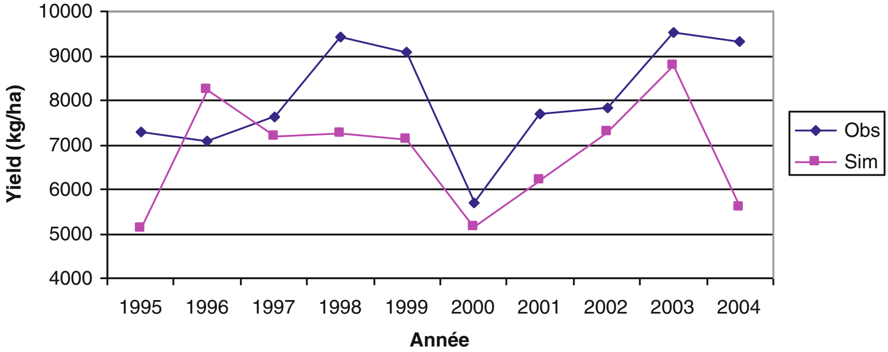


Fig. 4.5 Graphical representation of the results of the crop validation process for the municipality of Saint-Sébastien

this reason, it would be necessary to re-define some of the criteria related to the impacts of killing frosts on corn yields.

2. Quality of input data: Data on planting dates and solar radiation have a certain margin of error that influences the yields simulated by the model. Some planting dates estimated using mean temperature and precipitation have been too early in some years and have not always corresponded to the realities on the ground. The inclusion of additional criteria that take into account the soil moisture conditions would contribute to a better estimate of sowing dates.
3. Yield determinants: The simulations did not take into account the influence of diseases, insects and weeds on corn yields. As the simulations undertaken have considered water as the only limiting factor, it was almost impossible to reproduce the observed yields for these years during which corn productivity was greatly influenced by these factors.
4. Quality of yield data used for model calibration and validation: There may be a certain margin of error in the observed yields inherent to the methods used during the data collection process. In other words, the accuracy of crop yield statistics greatly depends on the adopted methodological approach. The differences between crop statistics provided by various institutions in Quebec show clearly the influence of the methodological approach on corn yields time series.

As can be seen in Figs. 4.4 and 4.5, the differences between simulated and observed yields were particularly large for the years 1999, 2002, 2004 and 2005 in Sainte-Martine and during the years 1998, 1999 and 2004 in the municipality of Saint-Sébastien. A thorough analysis of the farming conditions for those years might prove very useful in explaining the values of the statistical parameters considered during the crop model validation process. However, it is also important to remember that the data used to validate the model did not come from experimental plots and that any interpretation of the accuracy of the model based on the values of “d” and “RD” must take this aspect into account.

Table 4.3 Corn water-limited yield change (%) for the municipality of Sainte-Martine (2010–2039 period)

	Reference cultivar		Improved cultivar	
Climate scenario	With CO_2	Without CO_2	With CO_2	Without CO_2
Hot and dry	−4	−13	14	2
Hot and humid	−7	−13	9	1
Cold and dry	−3	−10	14	5
Cold and humid	12	7	20	15
Median	2	−4	22	14

Table 4.4 Corn water-limited yield change (%) for the municipality of Saint-Sébastien (2010–2039 period)

	Reference cultivar		Improved cultivar	
Climate scenario	With CO_2	Without CO_2	With CO_2	Without CO_2
Hot and dry	−2	−8	27	19
Hot and humid	−7	−10	20	16
Cold and dry	3	−1	34	29
Cold and humid	8	5	42	36
Median	11	7	47	41

4.3.1 Assessment of Climate Change Impacts on Corn Water-Limited Yields

The results of the potential impacts of climate change on corn water-limited yields are summarized in the tables below. As shown in Tables 4.3 and 4.4, without the CO_2 fertilizing effect, with the exception of the "median" climate scenario for Saint-Sébastien and the "cold and humid" climate scenario for both municipalities, the relative yield changes using the reference cultivar for the 2010–2039 future period are negative. The largest decreasing trends, using the reference cultivar and without considering the CO_2 fertilizing effect, were found for the "hot and humid" climate scenarios in both municipalities.

Considering the CO_2 fertilizing effect and the reference cultivar, corn yields vary from one municipality to another. For the municipality of Sainte-Martine, these yields are decreasing for the "hot" and "cold and dry" climate scenarios. For the municipality of Saint-Sébastien, by considering the CO_2 fertilizing effect and the reference cultivar, a decrease is only observed for the "hot" climate scenarios. By considering the CO_2 fertilizing effect, the anticipated positive changes with the reference cultivar are relatively low and estimated below 15 %. The anticipated corn yield decreases can be explained largely by acceleration of maturation, including the grain filling phase, and to a lesser extent by a water deficit during some critical stages of plant growth. Tables 4.5 and 4.6 show the potential evolution of the "planting to physiological maturity" cycle and the "grain filling" phase in a warmer climate than that of the reference period. In general, a shortening of the

Table 4.5 Variation (in days) of "Planting to Physiological Maturity" and grain filling phases for the Municipality of Sainte-Martine

Climate scenario	Reference period		Future period simulated with reference cultivar		Difference (future-reference)	Difference (future-reference)
	PPM	GFP	PPM	GFP	PPM	GFP
Hot and dry	152	60	127	40	−25	−20
Hot and humid	156	64	132	43	−24	−21
Cold and dry	156	59	148	56	−8	−3
Cold and humid	160	63	134	44	−26[a]	−19
Median	149	59	128	40	−21	−19

PPM Planting to Physiological Maturity, *GFP* Grain Filling Phase
[a]Not significant for $\alpha = 0.05$; $p = 0.2931$

Table 4.6 Variation (in days) of "Planting to Physiological Maturity" and grain filling phases for the Municipality of Saint-Sébastien

Climate scenario	Reference period		Future period simulated with reference cultivar		Difference (future-reference)	Difference (future-reference)
	PPM	GFP	PPM	GFP	PPM	GFP
Hot and dry	155	53	132	35	−23	−18
Hot and humid	161	57	133	36	−28	−21
Cold and dry	162	56	135	37	−27	−19
Cold and humid	161	57	136	38	−25	−32
Median	153	51	131	35	−22	−16

"planting to physiological maturity" cycle is anticipated, including the grain filling phase. With the reference cultivar, this potential shortening could reach almost 4 weeks depending on the climate scenario considered. The anticipated temperature increase would be the cause of this acceleration of the corn maturation process. Higher temperatures would favor a shortening of the grain filling phase and therefore a decrease of corn yields. With such shortening, it can be concluded that the reference cultivars would be inappropriate to be able to take benefit of the length of the growing season in a relatively warmer climate. From this perspective, other cultivars can be considered likely to benefit from the anticipated climatic conditions.

Indeed, the differences between these improved cultivars and those of the reference period would be in terms of thermal time taken to complete the "silking to physiological maturity" phase, and the number of grains per plant. It would also be possible to consider smaller values of the grain filling rate in order to reduce the shortening of the grain filling phase in a warmer climate. The exercise was essentially to show and confirm that a warmer climate would accelerate the process of physiological maturity of corn and the need to find better adapted cultivars. From this perspective, in a warmer climate during the 2010–2039 future period, as shown in Tables 4.3 and 4.4 it would be possible to have some increase in corn yields if better adapted cultivars are considered. However, it seems that frost risks would be higher with these improved cultivars. In order to assess the statistical significance of the differences between crop development phases for both reference and future periods, the Mann-Whitney test available in the R computing environment (R Core Team 2014) was used. Only the differences for the "planting to physiological maturity" growing cycle for the "cold and humid" climate scenario in the municipality of Sainte-Martine are not statistically significant.

If the availability of new cultivars better adapted to the anticipated climate conditions is essential in order to reduce the negative impacts of climate change on corn water-limited yields, we must, however, highlight the point that their adoption is neither automatic nor straightforward. Indeed, as economic agents, the corn-growing farmers will look carefully at the benefits that they will have with these improved cultivars. Furthermore, they will look at the potential impacts of the adoption of these relatively late improved cultivars, and also the consequences that the introduction of these new cultivars will have not only on the timing of their agricultural activities and farm operations in general, but also on the prices of their product. In this regard, in their decision-making process they would also be very interested in knowing what their competitors in other provinces and the U.S. are doing. From this perspective, the process of developing new cultivars should, apart from agronomic considerations, try to take into account the socio-economic aspects of the characteristics of new and better cultivars under a relatively warmer climate during the 2010–2039 future period.

4.4 Conclusions and Recommendations

This study aimed to present the potential impacts of climate change on corn yields for two municipalities in the West Montérégie region, and to identify some adaptation options likely to reduce the potential impacts of this new stressor on corn productivity. With the reference cultivars, a decrease in corn yields is generally expected when the CO_2 fertilizing effect is not considered. However, by considering the CO_2 fertilizing effect, a slight increase in corn yields could be observed for some climate scenarios. The anticipated decreases in corn yields would be largely due to acceleration of the corn physiological maturity process, and to a lesser extent, to water stress during some critical phenological stages. The adoption of improved cultivars could foster an increase in corn yields under warmer climate conditions.

The results of this study should be considered as possible scenarios of corn yields for these municipalities during the 2010–2039 future period. The direction and magnitude of the climate change impacts on corn yields will depend on the ability of the sector to deal not only with the new climate conditions, but also with the dynamic socio-economic factors, including agricultural policy, market conditions and technological advances. The simulation exercise of climate change impacts on yields using dynamic crop models has provided a set of output parameters that can be used as decision support at the farm level. However, there is still room for improvements, including better consideration of the impacts of frost on yield components, improved representation of crop response to elevated atmospheric CO_2 concentration, and explicit inclusion of other corn productivity determinants.

References

Anothai, J., Patanothai, A., Pannangpetch, K., Jogloy, S., Boote, K. J., & Hoogenboom, G. (2008). Reduction in data collection for determination of cultivar coefficients for breeding applications. *Agricultural Systems, 96*, 195–206.

Bristow, R. L., & Campbell, G. S. (1984). On the relationship between incoming solar radiation and daily maximum and minimum temperature. *Agriculture Forest Meteorology, 31*, 159–166.

Bruce, S., Leedman, A., & Sims, J. (2006). The Australian National Agricultural Monitoring System – A national climate risk management application. The Australian Society of Agronomy. http://www.regional.org.au/au/asa/2006/poster/technology/4715_brucese.htm. Consulted on 8 May 2008.

Caya, D., & Laprise, R. (1999). A semi-implicit semi-lagrangian regional climate model: The Canadian RCM. *Monthly Weather Review, 127*, 341–362.

Fay, T. H., Greeff, J. C., Eisenberg, B. E., & Groenveld, H. T. (2006). Testing the model for one predator and two mutualistic prey species. *Ecological Modelling, 196*, 245–255.

Hoogenboom, G., Tsuji, G. Y., et al. (1995). Decision support system to study climate change impacts on crop production. In C. Rosenzweig, L. H. Allen Jr., L. A. Harper, S. E. Hollinger, & J. W. Jones (Eds.), *Climate change and agriculture: Analysis of potential international impacts* (ASA special publication no. 59, pp. 51–75). Madison: American Society of Agronomy.

Hunt, L. A., Pararajasingham, S., Jones, J. W., Hoogenboom, G., Imamura, D. T., & Ogoshi, R. M. (1993). GENCALC: Software to facilitate the use of crop models for analyzing field experiments. *Agronomy Journal, 85*, 1090–1094.

Institut de Recherche et de Développement en Agroenvironnement (IRDA). (2007). Base dedonnées pédologiques numériques.

Intergovernmental Panel on Climate Change (IPCC). (2001). Climate change 2001: The scientific basis. In Contribution of working group I to the third assessment report. p. 944.

Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment. Report of the*

Intergovernmental Panel on Climate Change [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller (Eds.)] (pp. 996). Cambridge/New York: Cambridge University Press.

IPCC. (2013). Summary for policymakers. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge/New York: Cambridge University Press.

Jones, J. W., Jagtap, S. S., Hoogenboom, G., & Tsuji, G. Y. (1990). The structure and function of DSSAT. In Proc. of ISBNAT Symp. Decision Support System for Agrotechnology Transfer., 17 October 1989 (pp. 1–14). Hawaii Univ., Honolulu.

Jones, J. W., Hoogenbon, G., et al. (2003). The DSSAT cropping system model. *European Journal of Agronomy, 18*, 235–265.

La Financière Agricole du Québec. (2000). L'état des cultures au Québec. Rapport final 2000.

Martre, P., Wallach, D., Asseng, S., Ewert, F., Jones, J. W., Rötter, R. P., Boote, K. J., Ruane, A. C., Thorburn, P. J., Cammarano, D., Hatfield, J. L., Rosenzweig, C., Aggarwal, P. K., Angulo, C., Basso, B., Bertuzzi, P., Biernath, C., Brisson, N., Challinor, A. J., Doltra, J., Gayler, S., Goldberg, R., Grant, R. F., Lee, H., Hooker, J., Hunt, L. A., Ingwersen, J., Izaurralde, R. C., Kersebaum, K. C., Müller, C., Kumar, S. N., Nendel, C., O'leary, G., Olesen, J. E., Osborne, T. M., Palosuo, T., Priesack, E., Ripoche, D., Semenov, M. A., Shcherbak, I., Steduto, P., Stöckle, C. O., Stratonovitch, P., Streck, T., Supit, I., Tao, F., Travasso, M., Waha, K., White, J. W., & Wolf, J. (2014). Multimodel ensembles of wheat growth: Many models are better than one. *Global Change Biology, 21*(2), 911–925.

Mayer, D. G., & Butler, D. G. (1993). Statistical validation. *Ecological Modelling, 68*, 21–32.

Ministère de l'Agriculture des Pêcheries et de l'Alimentation du Québec (MAPAQ). (2006). Profil bioalimentaire de la Montérégie. 92p.

Morissette, H. (1972). *Les conditions du développement agricole au Québec*. Québec: Les Presses de l'Université Laval.

Music, B., & Caya, D. (2007). Evaluation of the hydrological cycle over the Mississipi river Bassin as simulated by the canadian regional climate model (CRCM). *Journal of Hydrometeorology, 8*, 969–988.

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., & Zhang, H. (2013). Anthropogenic and natural radiative forcing. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge/New York: Cambridge University Press.

Parry, M., Rosenzweig, C., Iglesias, A., Fischer, G., & Livermore, M. (1999). Climate change and world food security: A new assessment. *Global Environmental Change, 9*, S51–S67.

Plummer, D. A., Caya, D., Frigon, A., Cote, H., Giguere, M., Paquin, D., Biner, S., Harvey, R., & de Elia, R. (2006). Climate and climate change over North America as simulated by the Canadian RCM. *Journal of Climate, 19*(13), 3112–3132.

R Core Team. (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.URL http://www.R-project.org/

Ritchie, J. T., Singh, U., Godwin, D. C., & Bowen, W. T. (1998). Cereal growth, development and yield. In G. Y. Tsuji, G. Hoogenboom, & P. K. Thornton (Eds.), *Understanding options for agricultural production* (pp. 79–88). Dordrecht: Kluwer Academic Publishers.

Savoie, M. (2006). *Étude du caractère local des impacts du changement climatique sur les rendements en agriculture au Québec. Travail de maîtrise*. Québec: Département de géographie, Université de Montréal.

Tsuji, G. Y., Hoogenboom, G., & Thornton, P. K. (1998). *Understanding options for agricultural production*. Dordrecht: Kluwer.

van Ittersum, M. K., Leffelaar, P. A., van Keulen, H., Kropff, M. J., Bastiaans, L., & Goudriaan, J. (2003). On approaches and applications of the Wageningen crop models. *European Journal of Agronomy, 18*, 201–234.

Vanclay, J. K., & Skovsgaard, J. P. (1997). Evaluating forest growth models. *Ecological Modelling, 98*, 1–12.

Villeneuve, C., & Richard, F. (2007). Vivre les changements climatiques: Quoi de neuf? Éditions MultiMondes

Wood, R. (2008). Natural ups and downs. *Nature, 453*, 43–44.

Kénel Délusca is an agronomist engineer by training; his PhD is in Physical Geography (University of Montreal) with a specialization in climatology. Dr. Délusca was project coordinator and a postdoctoral fellow at the Laboratory of Sustainable Development and Territorial Dynamics within the Department of Geography (University of Montreal) where he worked on the assessment of the impacts of climate variability and change on agriculture in Quebec and Eastern Ontario and on the co-construction of adaptation policies and programs. Between 2013 and 2015, he was a visiting scholar at the Geography Department of Université de Montréal and Research Engineer at the French National Institute for Agricultural Research (INRA). Dr. Délusca has published several scientific papers and produced several reports related to the assessment of climate change impacts on agriculture and coastal zones with a focus on water issues. He is actually Adjunct Professor at the Institut des Technologies et des Études Avancées d'Haïti (ISTEAH) and Team Leader of the Technical Assistance to an European Climate Change-funded project in Haiti. His research interests are: climate change vulnerability assessment, high-resolution climate scenario elaboration, crop modeling, climate change policy, environmental evaluation, and multi criteria analysis.

Christopher R. Bryant received his doctorate in 1970 at the London School of Economics and Political Science (LSE), London. He was progressively Assistant, Associate and Full Professor in Geography at the University of Waterloo (1970 à 1990), then Full Professor in Geography the University of Montréal (1990 à 2014), and is now Adjunct Professor in Geography at the University of Montréal and also in the School of Environmental Design and Rural Planning, University of Guelph. He is one of the international leaders in research on urban/periurban agricultures (Canada, Western Europe and elsewhere), and he is also a recognized leader in the domain of adaptation of human activities (and especially agriculture) to climate change and variability, in local and community development, and in the strategic planning for local and regional development for and by citizens.

Chapter 5
The Economic Impact of Climate Change on Cash Crop Farms in Québec and Ontario

Paul J. Thomassin and Ning An

Abstract This chapter examines the economic impact of alternative climate change scenarios on representative cash crop farms in Quebec and Ontario. Mixed Integer Dynamic Linear Programming models were used to determine the annual optimal land and labour allocations over a 30 year time horizon. In the modeling process, five climate scenarios were modeled, along with different combinations of CO_2 enhancement and water limitation. Parameters, such as crop prices, costs of production, and crop yields, were simulated and projected into the future using various methods, such as Monte Carlo simulation, Crystal Ball Predictor and the Decision Support System for Agro-Technology Transfer cropping system model. Rotation and diversification constraints, as well as participation in public risk management programs were also incorporated into the optimization procedures. The results indicate that the economic impact of climate change varied by climate scenario, climate condition and region. Climate condition, i.e. CO_2 enhancement and water limitation, had a larger impact on net farm income than the climate scenarios. Technology development, in terms of crop variety improvement as well as the public insurance programs in terms of individual crop insurance, income stabilization insurance and AgriInvest, are adaptation strategies that can contribute to reducing the economic vulnerability to climate change.

Keywords Climate change • Mixed integer dynamic linear programming • Financial resilience • Technological change • Institutional change

5.1 Introduction

Annual weather conditions provide an element of risk in agricultural production and this risk increases with the inherent uncertainty associated with climate change (Parry et al. 2007). Agricultural producers have to face risks associated with weather, changes in the demand and supply in commodity markets, and the fluctuations in the Canadian dollar which makes input costs and market prices

P.J. Thomassin (✉) • N. An
McGill University, Montreal, QC, Canada
e-mail: paul.thomassin@mcgill.ca; ning.an@mail.mcgill.ca

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_5

difficult to predict. As a result, agricultural producers would benefit from taking a proactive approach to decision making where they take a systematic and integrated risk management approach when considering future climate change scenarios. Risk management tools; such as improved information, technology, crop insurance programs, and diversification of crops, can be used not only to adjust to climate change but also to take advantage of future opportunities that may arise. Difficulties can arise, however, when farmers try to obtain sufficient and reliable information regarding climate change and future market conditions in order 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; while the benefits are less visible and tend to be underestimated. If producers fail to understand and adapt to the stochastic nature of climate change due to a lack of resources or planning, they will suffer not only the negative effects on their production and marketing, but also the lost opportunity from the potential benefits.

Agriculture has changed over the past decades and remains an important sector for many Québec and Ontario rural communities. These communities will become more vulnerable if climate change results in a decrease in the economic activity from agriculture. On the other hand, the agriculture sector has become more technically sophisticated with developments such as more advanced crop varieties, better machinery and land management practices, all of which have resulted in increased yields.

Most of the studies that have focused on climate change and agriculture have used average conditions or scenarios using a static or partial equilibrium approach (e.g. van Zon and Yetkiner 2003; Schlenker and Roberts 2009; Kokoski and Smith 1987), which exclude indirect and general equilibrium effects, such as changes in market prices and the interdependence of climate effects (Arndt et al. 2012). As a result, previous climate change studies often only provide global or regional assessments and ignore the potential benefits from adaptation policies implemented at different institutional levels (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 producers' economic vulnerability under different climate scenarios, as well as the economic effects resulting from technology developments and institutional adaptation.

5.2 Previous Research

5.2.1 Influence of Climate Change

The causes and consequences of climate change are diverse (Tol 2009). Risks faced by producers can be divided into two main categories, those associated with the production process and those associated with the market (Antón et al. 2011). Taking the risk to production processes first, it has been demonstrated that crop yield changes due to climate change will vary by climate scenario, crop variety (Hareau et al. 1999) and agricultural region (Brassard and Singh 2008). The main causative factors controlling crop yield tend to be the same. One is the direct CO_2 fertilization effect from climate change (Alexandrov et al. 2002), which would benefit C_4 crops, such as corn and sorghum (El Maayar et al. 1997). The other is the indirect CO_2 effect that causes an increase in temperature which accelerates crop maturation, changes in soil moisture and nitrogen supply, and thus agricultural performance (Brassard and Singh 2008). Climate change factors that affect crops are usually interdependent and it is difficult to isolate and recognize their individual effects. This phenomenon will lead to a dilution of the effects of climate change to some extent, or even a cancellation of the impact of some individual factors (Brassard and Singh 2008).

Apart from the above mentioned technical effects resulting from climate change, climate change variables 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 and energy, will also be affected (Seyoum-Edjigu 2008), and will lead to a reallocation according to comparative advantage (Rosenzweig and Hillel 2007). Furthermore, increased uncertainty will strengthen the development of international markets (Fleischer et al. 2008) with some economic costs occurring as regions adapt to climate. 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 et al. 2003: 94), thus it is the "inter-annual and intra-annual variation" and extreme events, along with the complexity of agriculture, which determine the critical climatic thresholds and should be accounted for in risk averse models (Bryant et al. 2000).

5.2.2 *Economic Approach*

Apart from the modeling of physical and biological processes in agriculture, social-economic parameters representing human behaviour and cognition should be identified (Andersen and Mostue 2012; Just 2001). Optimization models that maximize a producer's profits are often used to represent the producer's behaviour in an economic decision model that can also integrate crop growth model information (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 addresses 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 producer's net income.

5.2.3 Adaptation Strategies

Adaptation to climate change must take into consideration both technical and social dimensions of the problem in order to be successful (Costello et al. 2010: 8). Adaptation research is an action-oriented undertaking where mutual learning among participants is required at the farm, economic and institutional levels (Jones and Preston 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. For example, a producer's 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). Economies of scale have 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 agricultural products are well-developed (Fleischer et al. 2008), either regionally or internationally. Economic adaptation strategies, such as investment, should not only be in new technologies and infrastructure construction, but also in the development of both input and output markets (Easterling 1996).

Changes in institutional structures and relationships can also be used to reduce climate change risks and thus agricultural vulnerability (Antón et al. 2011). 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 or producer 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). Existing institutional adaptation frameworks include several interrelated steps which assess the fundamental goals and resilience of individuals in the face of adverse events. These include 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 to adaptation (World Bank 2013). The insurance system has been the primary risk governance tool for industrialized society (Phelan et al. 2011). Both the UN Climate Convention and the Kyoto Protocol have included insurance as a mechanism for risk reduction to deal with the risk of natural disaster and the management of 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 producers to insure their crops and bring their interests and concerns to the attention of policymakers while always paying attention to the possibility of encouraging maladaptation (Schmitz et al. 2010).

In addition, an understanding of cross-level interactions (Phelan et al. 2011) are important since trade-offs and synergies can take place with collective action. For example, if producers' financial losses are limited by government policies they may show an increased willingness to accept yield losses and thus shift from risk-averse to risk-seeking behaviour (Reilly et al. 2003). On the other hand, producers' may have perceived the risks and opportunities associated with climate change and made technical improvements in their operations. Climate change should be regarded as a long-term phenomenon and the strategies required to address this issue should not only be at the farm level, but also at the institutional level (Bryant et al. 2000). Changes at institutional and political levels can result in government failure, which can be defined in terms of its limited ability to maintain long-term policies. If this occurs, government failure will increase the uncertainties associated with agricultural production and producers' costs (Schmitz et al. 2010). The potential co-benefits of adaptation and mitigation strategies (Kenny 2011) are the 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).

5.3 Research Design and Data Description

Four major cash crops were assumed to be cultivated on the representative farms at the selected sites (Ste-Martine and St-Sebastien in Quebec, and North Dundas in Ontario). They were grain corn, wheat, barley and soybean. There were two cultivars for each crop being simulated over the 30 year time period, 2010–2039. The reference cultivar is the currently grown cultivar and their performance and yields were validated by comparing the simulated values from the Decision Support System for the Agro-Technology Transfer model with the observed values. The other is an improved cultivar that was conceived in terms of more suitable thermal timing for some phenological stages and growth genetic coefficients, notably the grain filling rate. As for the cultivation practices, conventional tillage is the predominant tillage practice in these regions and was assumed to continue over the study's time period.

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.[1] In addition, these five scenarios were modified to include with and without CO_2 enhancement and with and without water limitation. Given these combinations 20 different climate scenarios and conditions were 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 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 a Hot and Dry scenario with CO_2 enhancement and water limitation in the first year, then this scenario would last over the following projected 29 years.

The Decision Support System for Agro-Technology Transfer (DSSAT) model was used by the Geography Department of the University of Montreal to simulate future crop yields for all scenarios, sites and crop varieties. The output from this model becomes an input into the mathematical programming models which were used to analyse the economic impact of climate change and agricultural vulnerability. A brief structure of the process of analysis for this study is described in Fig. 5.1.

5.3.1 Data Prepared

5.3.1.1 Projected Prices and Costs

It was assumed that producers were price takers in regional, national and international markets. Future prices over the planning horizon were projected using historical prices over the period 1985–2010. Various methods, such as Crystal Ball's CB Predictor (v.11.1.2.2) (Werchman and Crosswhite 2006) and Monte Carlo (MC) simulation, were used to project these prices. The trends and variability in crop prices in both provinces are summarized in Fig. 5.2.

CB Predictor and Monte Carlo simulations were also used to simulate the cost of production (COP) for each crop into the future. Provincial COP data from La Financière Agricole du Québec since 1999 were used to reflect the budgets at the

[1] They were chosen to represent different agro-climatic indices prepared by climatologists at 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 an increase in temperature and a decrease in the precipitation pattern.

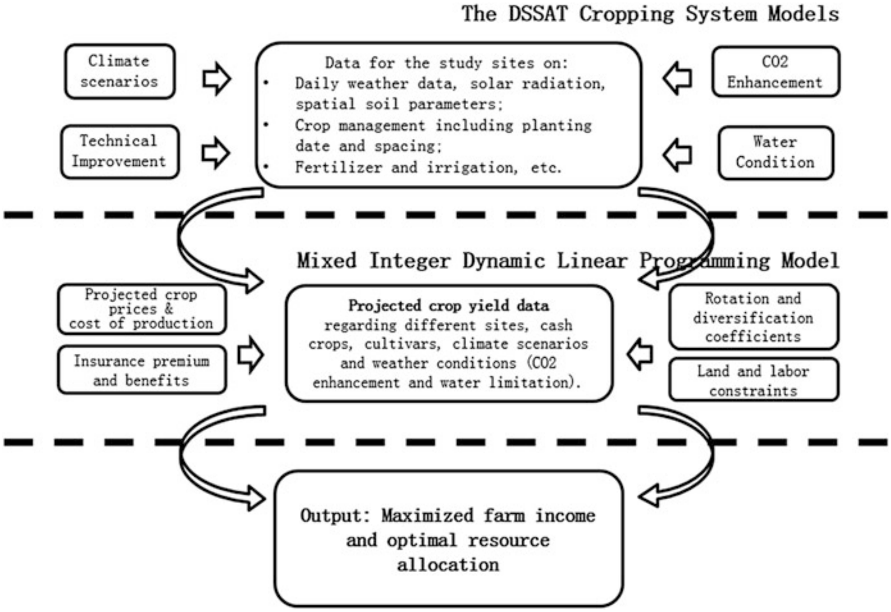


Fig. 5.1 Structure of the analysis process

Ste-Martine and St-Sébastien sites, after being adjusted for regional costs from the Centre d'Expertise en Gestion Agricole (Tremblay 2013). In North Dundas, the Field Crop Budgets from the Ministry of Agriculture, Food and Rural Affairs (OMAFRA 2013) and the Ontario Farm Input Price Index (Statistics Canada, 2013) since 1971 were used to make the projections. In this study, the cost per hectare for each of the four crops includes both fixed costs and variable costs. 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 increase at a 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 the producers. Machinery depreciation was estimated and a zero residual value was assumed at the end of the planning horizon while maintenance costs were still included in the costs.

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 significant higher yields than the reference cultivar for each crop under most of the scenarios, conditions and sites. Therefore, the COP of the improved cultivars were adjusted by site and crop, as higher expenses for pesticides, drying, storage, fuel and electricity, and other expenses were expected.

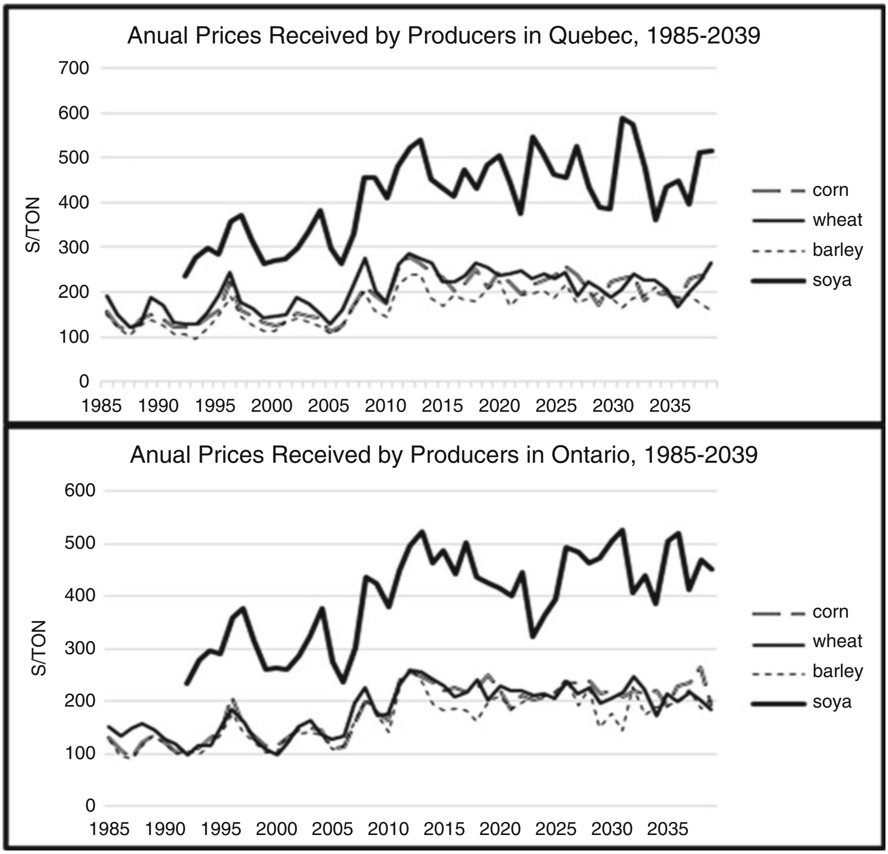


Fig. 5.2 Historical and projected crop prices in Québec and Ontario, 1985–2039. (Source: Fédération des producteurs de cultures commerciales du Québec (FPCCQ), Ontario Ministry of Agriculture and Food (OMAFRA), and Statistics Canada)

5.3.1.2 Crop Insurance Programs

Between 2000 and 2010 there was a 50 % increase in insured crop area in Montérégie West with grain corn representing 62 % 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 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 cost of production was initially adjusted on a per hectare basis using corresponding premiums and compensations depending on the difference between simulated yield and covered probable yield, which is the average projected yield of the previous 5-year period times the coverage rate.

The Farm Income Stabilization Insurance (ASRA) program (La Financière Agricole du Québec 2013) is similar to the Risk Management Program (RMP) in Ontario (Agricorp 2013) and provides protection against adverse market price fluctuations. The AgriStability program is based on the principle that governments share with the producer the cost of stabilizing annual income (La Financière Agricole du Québec 2013; Agricorp 2013). As long as the margin[2] drops by more than 30 % in relation to the reference margin[3] 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 % of their operation's adjusted net sales of allowable products and to receive a matching government contribution, as well as any accrued interest. 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 procedure, but their risk aversion capability will be evaluated based on the annual optimal farm performance.

5.4 Mixed Integer Dynamic Linear Programming Model

In order for producers to maximize their profits they have to make decisions concerning agricultural production, technology and economic activities. For example, producers have to make rotation and diversification plans, decide the seeding area for each crop and the amount of hired labour and insurance coverage. In addition, most of their decisions are subject to some constraints. Seeding area is limited by the total cultivable land, while hired labour depends on the number of labour hours available in a particular period. Insurance participation is also constrained by some qualification requirements set by the institutions. One method that is often used to solve such complex decision problems and provide for an

[2] Generally speaking, the production margin corresponds to the difference between the participating producer's farming revenue and costs (La Financiere Agricole du Québec).

[3] The reference margin corresponds to the Olympic average of the margin in the previous 5 years, which excludes the highest and lowest years.

optimal solution is a mathematical method called Linear Programming (LP). These models take the following form:

$$\text{Maximize} \quad Z = p_n^T S_n - c_n^T X_n - w_n l^T X_n, n = 1, 2, \ldots, 30 \tag{5.1}$$

$$\text{Subject to} \quad X_n I \leq b \tag{5.2}$$

$$l^T X_n \leq d \tag{5.3}$$

$$X_n \circ Y_n \geq S_n \tag{5.4}$$

$$X_{ij} \leq \mathrm{a} X_n I \tag{5.5}$$

$$\text{And} \quad X_n, S_n \geq 0 \tag{5.6}$$

Where the objective function Z (Eq. 5.1) is the net farm return that needs to be maximized, X_n is the cultivated area for each crop with different Individual Crop Insurance coverage at year n, S_n is the quantity of each crop sold in year n,[4] p_n, c_n and w_n represent the corresponding crop prices, cost of production (including the net payment to the Individual Crop Insurance plan) and the hourly wage for hired labour, and l is the labour requirement for each unit of cropland. Equations (5.2) and (5.3) are the land and labour constraints where b and d represent the total land and labour available for the representative farm, which are 350 ha and 4725 h[5] respectively. Y_n, Eq. (5.4), 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 can also 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. Equation (5.5) constrains the maximum acreage set for each crop in different years based on the rotation. To provide greater flexibility in choosing the most profitable annual production choice, these limits were set slightly higher than their actual shares. Through randomly adjusting the value of all variables subjected to all of the constraints and the non-negative requirement (Eq. 5.6), an optimal solution that maximizes the objective value can be estimated. Finally, some of the choice variables, such as land allocation and contract labour hours, are required to be integers.

[4] A minimum of 5 % of the total output for each crop will be stored for farm consumption according to historical data.

[5] This number was obtained from Centre d'études sur les coûts de production en agriculture.

5.5 Results

The mathematical programming model was optimized for each year of the 30 year period taking into account farm income from crop production and crop insurance programs, i.e. Individual Crop Insurance in Quebec and Production Insurance in Ontario. These values were then adjusted to take into account whether or not income stabilization payments would be paid out and for the contribution of the AgriInvest program. The present value of each of the 30 years of net farm income, crop insurance and income stabilization payments and AgriInvest were estimated using a 4.5 % discount rate. The results reported provide an estimate of the present value of the average annual net farm income with adjustments for insurance payouts of the representative farms for each of the climate scenarios.

A baseline analysis was undertaken that estimated the present value of the average annual net farm income[6] in the three different regions for the representative cash crop farms when there was no technical innovation; i.e. no improvement in the crop cultivars. The present value of the average annual net farm income varies by location, climate scenario and by climate condition; i.e. CO_2 enhancement and water limitation (Table 5.1). In Ste.-Martine the largest average annual net farm income occurs with the Hot and Dry climate scenario with CO_2 enhancement and no water limitation, while in St.-Sebastien the largest average annual net farm income occurs under the Median climate scenario with CO_2 enhancement and no water limitation. North Dundas receives the greatest average annual net farm income with the Cold and Humid climate scenario with CO_2 enhancement and water limitation.

Of the various factors that influence net farm income, the climate conditions of CO_2 enhancement and water limitation has the greatest influence. The difference in the percentage change in the average annual net farm income across the climate scenarios (Table 5.2) is less than the difference in the percentage change in average annual net farm income due to climate conditions within any one climate scenario for each region (Table 5.3). Ste.-Martine has the greatest difference between the highest and lowest average annual net farm income across the climate scenarios of the three regions. The largest variation is a 47 % change in average annual net farm income between the Median climate scenario and the Hot and Dry climate scenario when there is CO_2 enhancement and water limitation. The variations across the different climate scenarios are smaller in St.-Sebastien and North Dundas (Table 5.2).

The percentage change in average annual net farm income increases substantially within any one climate scenario with variations in climate conditions. In Ste.-Martine the greatest percentage difference in average annual net farm income occurs under the Cold and Dry climate scenario. Under this climate scenario the average annual net farm income differs by 77 % between the climate conditions

[6] In this section net farm income refers to income from crop production, crop production insurance payouts, adjustments made for income stabilization payouts and AgriInvest.

Table 5.1 Average annual present value of net farm income with no technological change but with institutional support (in '000 of Dollars)

		Climate scenarios				
Location	Condition	Hot and dry	Hot and humid	Median	Cold and dry	Cold and humid
Ste-Martine	CO_2 and no water limit	128.17	117.84	124.97	108.23	121.89
	CO_2 and water limit	33.65	59.97	63.54	50.03	61.42
	No CO_2 and no water limit	93.15	83.04	90.18	76.71	88.08
	No CO_2 and water limit	32.25	37.03	36.49	24.31	32.46
St-Sebastien	CO_2 and no water limit	123.65	116.40	124.34	108.86	119.04
	CO_2 and water limit	117.25	122.63	117.24	103.76	112.24
	No CO_2 and no water limit	83.85	77.55	84.31	71.75	79.85
	No CO_2 and water limit	76.49	80.26	77.06	65.32	71.56
North Dundas	CO_2 and no water limit	189.01	168.87	200.20	177.61	190.39
	CO_2 and water limit	167.44	174.62	180.48	179.69	200.42
	No CO_2 and no water limit	144.31	134.64	156.61	142.97	153.20
	No CO_2 and water limit	138.32	143.56	147.59	145.81	167.11

Table 5.2 Percentage change in net farm income across the five climate scenarios for each climate condition and region (percentage change)

Condition	Ste.-Martine	St.-Sebastien	North Dundas
CO_2 and no water limit	15.6	12.5	15.6
CO_2 and water limit	47.0	15.4	16.5
No CO_2 and no water limit	17.7	14.9	14.0
No CO_2 and water limit	34.4	18.6	17.2

Estimated by subtracting the smallest net farm income from the largest net farm income (Table 5.1) for a given climate condition across the climate scenarios and dividing by the largest net farm income

Table 5.3 Percentage change in net farm income across climate conditions for each climate scenario and region (percentage change)

Climate scenario	Ste.-Martine	St.-Sebastien	North Dundas
Hot and dry	74.8	38.1	26.8
Hot and humid	68.6	36.8	22.9
Median	70.8	38.0	26.3
Cold and dry	77.5	40.0	20.4
Cold and humid	73.4	39.9	23.6

Estimated by subtracting the smallest net farm income from the largest net farm income (Table 5.2) for a given climate scenario across the climate conditions and dividing by the largest net farm income

when you have CO_2 enhancement and no water limitation and when there is no CO_2 enhancement and water limitations (Table 5.3). The variation in average annual net farm income due to different climate conditions is smaller in St.-Sebastien and North Dundas as compared to Ste.-Martine; however, these difference are greater than those across the climate scenarios when the climate conditions are held constant (Table 5.2).

The impact of technological change, in terms of cultivar improvements, can be seen in Table 5.4. The average annual net farm income increases substantially in all locations and across all climate scenarios and conditions. The largest increases in average annual net farm income can be found in Ste.-Martine and St. Sebastien. In Ste.-Martine, the greatest average annual net farm income occurs under the Median climate scenario when there is CO_2 enhancement and no water limitation. This average annual net farm income is more than double the average annual net farm income when only the reference cultivar was available. In St.-Sebastien, the largest average annual net farm income occurs under the Median climate scenario with CO_2 enhancement and no water limitation when the improved cultivars are available. North Dundas has the highest average annual net farm income under the Median climate scenario and CO_2 enhancement and no water limitation. In all three regions, the lowest average annual net farm income occurs when there is no CO_2 enhancement and water limitation (Table 5.4).

To determine the impact of income insurance programs, ASRA in Quebec and RMP in Ontario, AgriStability and the AgriInvest program, these payments and

Table 5.4 Average annual present value of net farm income with technological change and with institutional support (in '000 of Dollars)

		Climate scenarios				
Location	Condition	Hot and dry	Hot and humid	Median	Cold and dry	Cold and humid
Ste-Martine	CO_2 and no water limit	263.80	238.42	269.61	241.52	261.54
	CO_2 and water limit	97.65	87.10	102.17	78.41	89.62
	No CO_2 and no water limit	231.15	202.02	237.36	213.64	230.56
	No CO_2 and water limit	57.50	52.89	59.87	47.25	56.35
St-Sebastien	CO_2 and no water limit	230.00	215.08	230.61	222.49	225.70
	CO_2 and water limit	162.96	164.18	160.39	146.08	154.18
	No CO_2 and no water limit	191.46	176.11	192.90	183.33	189.30
	No CO_2 and water limit	115.01	113.58	114.45	104.98	108.16
North Dundas	CO_2 and no water limit	252.21	226.07	265.51	238.46	252.51
	CO_2 and water limit	174.27	189.04	222.71	198.81	214.71
	No CO_2 and no water limit	195.79	183.32	210.85	193.80	204.86
	No CO_2 and water limit	161.49	151.87	173.42	158.81	169.30

benefits were subtracted from the average annual net farm income but allowing for technological change in terms of both the reference cultivar and the improved cultivar. It should be noted that the individual crop insurance programs were part of the optimized solution and thus included in net farm income. As expected, the average annual net farm income in this scenario is lower than the average annual net farm income when the income insurance programs, AgriStability, AgriInvest and technological change were included (Table 5.5). In all cases, the greatest net farm income occurs with the Median climate scenario and with CO_2 enhancement and no water limitation.

5.6 Conclusions

This study estimated the economic impact of climate change on representative cash crop producers in three regions in Quebec and Ontario. Five climate scenarios with four different combinations of climate conditions were analyzed. The impact of climate change varied by region, climate scenario and climate condition. The region that was least affected was North Dundas in Ontario, while the region most affected was Ste.-Martine in Quebec. The climate condition, i.e. whether or not there was CO_2 enhancement and/or water limitation, had a larger impact on average annual net farm income when compared to the climate scenarios.

Technological change, in terms of improved crop varieties, decreased farm financial vulnerability as compared to when only the reference crop varieties were available. Net farm income increased in all situations when farm operators had a choice of crop varieties between the reference varieties and the improved varieties. This increase was substantial in many of the scenarios. The investment in research and development into better crop varieties can be an important strategy for cash crop producers to adapt to climate change.

The models that were developed optimized net farm income taking into account production decisions and individual crop insurance decisions. In addition to individual crop insurance, the models also included income stabilization insurance, AgriStability and AgriInvest. Access to these additional risk management programs also increased average annual net farm income. Government and/or private income insurance and investment programs can play an important role in decreasing farm financial vulnerability to climate change and can be a risk management tool that can assist producers in adapting to climate change.

Table 5.5 Average annual present value of net farm income with technological change and individual crop insurance but no income insurance or agriInvest (in '000 of Dollars)

		Climate scenarios				
Location	Condition	Hot and dry	Hot and humid	Median	Cold and dry	Cold and humid
Ste-Martine	CO_2 and no water limit	254.03	230.35	259.62	230.27	252.70
	CO_2 and water limit	77.44	72.07	87.44	63.89	73.74
	No CO_2 and no water limit	221.92	194.84	228.18	202.31	222.35
	No CO_2 and water limit	41.29	38.00	42.73	34.74	41.71
St-Sebastien	CO_2 and no water limit	221.58	206.77	222.54	213.53	218.26
	CO_2 and water limit	155.15	155.74	150.59	139.49	146.81
	No CO_2 and no water limit	184.42	168.78	184.40	176.19	182.86
	No CO_2 and water limit	106.73	106.10	104.62	97.44	100.43
North Dundas	CO_2 and no water limit	239.39	212.05	251.28	225.10	238.79
	CO_2 and water limit	153.11	174.45	208.57	185.53	200.76
	No CO_2 and no water limit	181.16	166.85	194.70	179.99	190.31
	No CO_2 and water limit	144.93	133.88	156.21	144.00	153.91

References

Agricorp. (2013). *Insurance programs*. http://www.agricorp.com/en-ca/Programs/Pages/Default.aspx

Alexandrov, V., Eitzinger, J., Cajic, V., & Oberforster, M. (2002). Potential impact of climate change on selected agricultural crops in north-eastern Austria. *Global Change Biology, 8*(4), 372–389.

Andersen, S., & Mostue, B. A. (2012). Risk analysis and risk management approaches applied to the petroleum industry and their applicability to IO concepts. *Safety Science, 50*(10), 2010–2019.

Antón, J., Kimura, S., & Martini, R. (2011). *Risk management in agriculture in Canada*. Paris: Organisation for Economic Cooperation and Development.

Apland, J., & Hauer, G. (1993). *Discrete stochastic programming: Concepts, examples and a review of empirical applications* (Staff Paper Series). Minneapolis: Department of Agricultural and Applied Economics, University of Minnesota.

Arndt, C., Farmer, W., Strzepek, K., & Thurlow, J. (2012). Climate change, agriculture and food security in Tanzania. *Review of Development Economics, 16*(3), 378–393.

Brassard, J. P., & Singh, B. (2008). Impacts of climate change and CO_2 increase on agricultural production and adaptation options for Southern Québec, Canada. *Mitigation and Adaptation Strategies for Global Change, 13*(3), 241–265.

Bryant, C. R., Smit, B., Brklacich, M., Johnston, T. R., Smithers, J., Chjotti, Q., & Singh, B. (2000). Adaptation in Canadian agriculture to climatic variability and change. *Climatic Change, 45*(1), 181–201.

Ciriacy-Wantrup, S. V., & Bishop, R. C. (1975). Common property as a concept in natural resources policy. *Natural Resources Journal, 15*, 713–726.

Costello, C. J., Neubert, M. G., Polasky, S. A., & Solow, A. R. (2010). Bounded uncertainty and climate change economics. *Proceedings of the National Academy of Sciences, 107*(18), 8108–8110.

Easterling, W. E. (1996). Adapting North American agriculture to climate change in review. *Agricultural and Forest Meteorology, 80*(1), 1–53.

El Maayar, M., Singh, B., André, P., Bryant, C. R., & Thouez, J. P. (1997). The effects of climatic change and CO_2 fertilisation on agriculture in Québec. *Agricultural and Forest Meteorology, 85*(3–4), 193–208.

Fleischer, A., Lichtman, I., & Mendelsohn, R. (2008). Climate change, irrigation, and Israeli agriculture: Will warming be harmful? *Ecological Economics, 65*(3), 508–515.

Hareau, A., Hofstadter, R., & Saizar, A. (1999). Vulnerability to climate change in Uruguay: Potential impacts on the agricultural and coastal resource sectors and response capabilities. *Climate Research, 12*, 185–193.

John, M., Pannell, D., & Kingwell, R. (2005). Climate change and the economics of farm management in the face of land degradation: Dryland salinity in Western Australia. *Canadian Journal of Agricultural Economics Revue Canadienne D'Agroeconomie, 53*(4), 443–459.

Jones, R. N., & Preston, B. L. (2011). Adaptation and risk management. *Wiley Interdisciplinary Reviews: Climate Change, 2*(2), 296–308.

Just, R. E. (2001). Addressing the changing nature of uncertainty in agriculture. *American Journal of Agricultural Economics, 83*(5), 1131–1153.

Kenny, G. (2011). Adaptation in agriculture: Lessons for resilience from eastern regions of New Zealand. *Climatic Change, 106*(3), 441–462.

Kokoski, M. F., & Smith, V. K. (1987). A general equilibrium analysis of partial-equilibrium welfare measures: The case of climate change. *American Economic Review, 77*(3), 331–341.

La Financière Agricole du Québec. (2010). *Statistics and rates: Crop insurance*. http://www.fadq.qc.ca/en/statistics_and_rates.html

La Financière Agricole du Québec. (2013). *Insurance and income protection*. http://www.fadq.qc.ca/en/insurance_and_income_protection/stabilization_insurance/program.html

Lehmann, N., Finger, R., Klein, T., Calanca, P., & Walter, A. (2013). Adapting crop management practices to climate change: Modeling optimal solutions at the field scale. *Agricultural Systems, 117*, 55–65.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science, 319* (5863), 607–610.

May, B., & Plummer, R. (2011). Accommodating the challenges of climate change adaptation and governance in conventional risk management: Adaptive collaborative risk management (ACRM). *Ecology and Society, 16*(1), 47. http://www.ecologyandsociety.org/vol16/iss1/art47/

OMAFRA. (2013). Field crop budgets, Publication 60, the Ministry of Agriculture, Food and Rural Affairs Publishing, Toronto:Ontario. http://www.omafra.gov.on.ca/english/busdev/facts/pub60.pdf

Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J., & Hanson, C. E. (2007). *Climate change 2007: Impacts, adaptation and vulnerability*. Cambridge: Intergovernmental Panel on the Convention for Climate Change.

Perman, R., Yue, M., McGilvray, J., & Common, M. (2003). Concepts of sustainability. In *Concepts of ustainability*. Toronto: Pearson.

Phelan, L., Taplin, R., Henderson-Sellers, A., & Albrecht, G. (2011). Ecological viability or liability? Insurance system responses to climate risk. *Environmental Policy and Governance, 21*(2), 112–130.

Pukkala, T., & Kellomäki, S. (2012). Anticipatory vs adaptive optimization of stand management when tree growth and timber prices are stochastic. *Forestry, 85*(4), 463–472.

Reilly, J. M. (1999). Climate change and agriculture: The state of the scientific knowledge. *Climatic Change, 43*(4), 645–650.

Reilly, J., Tubiello, F., McCarl, B., Abler, D., et al. (2003). U.S. agriculture and climate change: New results. *Climatic Change, 57*(1–2), 43–67.

Rosenzweig, C., & Hillel, D. (2007). Agriculture and climate change: Effects and responses. *Phi Kappa Phi Forum, 87*(1), 19–24.

Roshani, E., MacLeod, S., & Filion, Y. (2012). Evaluating the impact of climate change mitigation strategies on the optimal design and expansion of the Amherstview, Ontario, Water Network: Canadian case study. *Journal of Water Resources Planning and Management, 138*(2), 100–110.

Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to U.S. Crop yields under climate change. *Proceedings of the National Academy of Sciences, 106* (37), 15594–15598.

Schmitz, A., Moss, C. B., Schmitz, T. G., Furtan, H. W., & Schmitz, H. C. (2010). *Agricultural policy, agribusiness and rent-seeking behaviour* (2nd ed.). Toronto: University of Toronto Press.

Seyoum-Edjigu, E. (2008). What does the future have in store for farmers in Québec?: Economic impacts of climate change on cash crop farms in the Montérégie West and Saguenay Lac St-Jean. Master thesis. Department of Agricultural Economics, McGill University, Montréal, QC

Statistics Canada. (2013). *Farm input price index*. http://www5.statcan.gc.ca/cansim/pick-choisir

Tol, R. S. J. (2009). The economic effects of climate change. *Journal of Economic Perspectives, 23*(2), 29–51.

Tremblay, C. (2013, January). Centre d'expertise en gestion agricole. Personal e-mail communication

van Zon, A., & Yetkiner, I. H. (2003). An endogenous growth model with embodied energy-saving technical change. *Resource and Energy Economics, 25*(1), 81–103.

Werchman, C., & Crosswhite, C. (2006). *CB predictor user manual*. Oracle Corporation, Denver: Colorado.

Wilcock, R., Elliott, S., Hudson, N., Parkyn, S., & Quinn, J. (2008). Climate change mitigation for agriculture: Water quality benefits and costs. *Water Science and Technology, 58*(11), 2093–2099.

World Bank. (2013). *World development report 2014: Risk and opportunity*. World Bank Publishing. http://elibrary.worldbank.org/doi/abs/, 10.1596/9780821399033_Focus

Paul J. Thomassin is an Associate Professor of Agricultural Economics at McGill University. He received his B.Sc. (Agr.) from McGill University and his M.S. and Ph.D. in Agricultural and Resource Economics from the University of Hawaii at Manoa. He is a director of the McGill Centre for the Convergence of Health and Economics, a Research Fellow at the Centre for Interuniversity Research and Analysis Analysis of Organizations (CIRANO) with the Experimental Economics Group and was a Visiting Professor at the William S. Richardson, School of Law, at the University of Hawaii, Visiting Fellow at the National Centre for Development Studies at the Australian National University, and Honorary Professor in the Division of Science and Technology at the University of Auckland. His research interest include: the impact of climate change on agriculture, carbon offset trading, incorporating the environment into agricultural decision making, macroeconomics analysis of agriculture, health and trade policies, and non-market valuation of the environment.

Ning An received her Master of Science degree in Agricultural Economics from McGill University. Her main research interest lies in the economic impact of climate change on Canadian farms.

Chapter 6
The Organizational Dimensions of Agricultural Adaptation: Experiences in Québec's Market Garden Sector

Annie Choquette, Nicolas Milot, and Laurent Lepage

Abstract Current and future climate change might force agriculture activities to adapt to new climatic stimuli. Southeast of the watershed of the River Châteauguay in Quebec (CAN), Norton Creek's watershed is characterized by the presence of organic soils which are very fertile and adapted to the growing of vegetable crops. The increased frequency of extreme events affects farmers and encourages them to develop or promote mainly individual and technical adaptation measures.

This research is a case study focusing on the characteristics of the actors' networks in the vegetable growing sector. We analyze adaptation measures already in place or potentially coming as well as the possible integration of adaptation to climate change to integrated watershed management in Québec. Three main issues are addressed: (1) irrigation; (2) maintenance and overflow of rivers; and (3) control of pests and diseases. We report on communication problems between some key actors, strategies adopted by stakeholder groups to deal with formal constraints, the importance of economic factors in the decision-making process and the need to reduce uncertainty regarding climate changes impacts for many stakeholders.

Keywords Adaptation • Agriculture • Water • Social dynamics

6.1 Introduction

In Québec's agricultural sector, the urgent need to respond to climate change, particularly with respect to hydroclimatic conditions, is confronted with a complex institutional framework. Furthermore, the networks made up of farmers, civil servants and other players in the agricultural sector generate special social dynamics.

As in many other regions worldwide, the institutional framework regulating agriculture in Québec is highly fragmented. Agricultural practices are governed

A. Choquette (✉) • N. Milot • L. Lepage
Université du Québec à Montréal, Montreal, QC, USA
e-mail: annie.choquette86@gmail.com; milot.nicolas@uqam.ca; lepage.laurent@uqam.ca

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_6

by laws, policies and regulations that are the responsibility of the Agriculture, Fisheries and Food Department (MAPAQ); the relationships between these sets of rules and “water management” fall within the purview of the Sustainable Development, Environment, Wildlife and Parks Ministry (MDDEFP), and are administered by regional county municipalities—MRC. Furthermore, watershed conservation organizations (OBVs) which are in charge of implementing integrated watershed management (IWM) may also be involved.

The search for adaptation strategies is complicated by many layers of intervention and decision-making from the farmers’ land to regional and/or specialized groups of producers, to the entire agricultural sector of the province. In addition, various institutional clusters control how adaptation issues are defined in terms of the management of agriculture, water or climate change.

This chapter explores this complexity and sheds light on the challenges and opportunities inherent with the implementation of strategies to adapt to changes in hydrological conditions by Québec’s market garden sector. Following a brief description of the research project, the case study and theoretical framework used, the main organizational phenomena observed and their consequences with respect to the implementation of adaptation strategies are presented. We focus on the recognition of the substantive issues faced by the various actors, and on the ability or inability to define potential adaptation actions. We also look at how the nature of their interrelational network affects the ability of the market garden sub-sector under study to adapt and how these interactions among significant actors results in certain strategies being prioritized.

6.2 Research Project, Case Study and Theoretical Framework

The observations and analysis presented in this chapter stem from a project carried out between 2011 and 2013 dealing with the challenges of integrating adaptation to climate change into watershed management efforts in Québec (Milot et al. 2013). As part of the programming of the Ouranos Consortium on Regional Climatology and Adaptation to Climate Change, and funded under the scope of the activities of Québec’s 2006–2012 climate change action plan, the project’s objective was to stimulate discussion about adaptation to climate change among those responsible for water management and local stakeholders: farmers, civil servants and the OBV, who are in charge of the effective implementation of water management by watershed. For the most part, this research project was based on case studies of different contexts in which climate change is impacting water resources. One of the studies focused on the social and political dimensions of the challenges of adapting market garden practices to climate change in the Montérégie region, situated in the Norton creek watershed, a sub-watershed of the Châteauguay River.

The SCABRIC (the French acronym for the "Organization for the conservation and development of the Châteauguay river watershed" (Fig. 6.1)) is the organization mandated to implement IWM in the Châteauguay watershed and including therefore, the Norton creek watershed. Following Quebec's model of IWM, the SCABRIC has had to produce a "water plan" in which local stakeholders and users recognize issues, solutions and actions that they have to undertake. Stakeholders' participation is voluntary and the water plan is elaborated through collective deliberation (on a board allowing an equal presence of municipal representatives, economic interests, and community representatives). Technically, the OBV's workers has to collect all data and scientific knowledge about water issues, to create a momentum among local actors to provide active participation, to support deliberation and water plan elaboration, and finally, to follow the implementation of the actions listed in the plan. The Quebec IWM model is non-coercive, does not replace elements of the legal framework and OBVs must not take the place of existing local organizations which have responsibilities or a mandate for performing actions related to water use and management.

Fig. 6.1 The Chateauguay watershed area

6.3 Case Study Context

The soil type of the Norton creek watershed is essentially black earth, also referred to as organic or muck soil (chernozem) resulting from the decomposition of ancient peat bogs resting on layers of relatively impermeable sediments. At the end of the 1940s, intensive market gardening began in the muck soils of the region (Lépine 1973). In 2010, vegetable production was the fourth largest agricultural venture in the Montérégie in terms of revenues. Market gardening is concentrated mainly in the MRC of the Jardins-de-Napierville (mainly vegetable, apple and berry crops).

Opening up large tracts of land to agriculture has led to accelerated soil oxidation and compaction. As a result, these organic soils are now very vulnerable to wind and water erosion and there is a net loss of topsoil, corresponding to between 1 and 3 cm (FPMQ 2006).

Following tropical storm Irene in 2011, exports dropped significantly, and there were serious losses. This devastating event appears to have helped raise awareness of the problems related to climate change. At the same time, the Ouranos Consortium published several studies about the impact of climate change on the region's hydrographic network and its precipitation regime, studies that were repeated by the SCABRIC, in its *Portrait du bassin versant de la rivière Châteauguay* (Portrait of the Châteauguay river watershed: Ouranos 2010; Audet et al. 2010; Côté et al. 2006). This study found that increased precipitation from snow and rain in southwestern Québec should not exceed 8 %. Changes in seasonal rain inputs could be higher. Spring flooding should be earlier, which would increase inputs in March, April and May. The summer low water levels of waterways should become even lower because of increased evapotranspiration and earlier spring flooding. Extreme weather events could vary in frequency and intensity. In addition, the studies carried out by the Centre d'expertise hydrique du Québec (Hydric Expertise Center) concluded that by 2050, irrigation needs in the region could increase by 10–20 % (Cyr et al. 2012).

The Ouranos Consortium also established that the combination and accumulation of different climatic stresses could make plants more vulnerable to disease (Ouranos 2010). Pathogen and insect populations could also change in conjunction with the temperature and humidity changes forecasted. However, it is difficult to estimate the extent of these changes, and of gains and losses in agricultural yields, because of the unpredictable adaptation capacities of the various insect or pathogen populations.

Most market gardeners interviewed stated that they were already experiencing the effects of climate change. Flooding of waterways, already frequent and problematic in the region, is their main concern, as are the changing populations of market garden crop pests and the timing of irrigation (Papineau et al. 1993).

6.4 Theoretical and Methodological Framework

Adapting market garden practices to climate change is dependent on the evolution of the biophysical characteristics of ecosystems, as much as on as the characteristics of the network of stakeholders and institutions that structure regional agricultural practices. The analysis framework used has therefore been designed to take institutional and organizational factors into account.

We began by drawing up a portrait of formal institutions in the regional market garden sector and in water management, using the institutional analysis and development framework approach (Ostrom 2005). This made it possible to highlight the interrelationships among the various institutional components (objectives, scope, scale of application, roles of actors, information management and spinoffs . . .) in order to observe whether institutions support or run counter to each other's activities and to assess the potential opportunities for social actors.

We then analyzed the organizational dynamic underlying the group of stakeholders concerned with the issue of water management in the study sector. Nineteen semistructured interviews were carried out (12 with market garden producers in the region and 7 with MAPAQ, MDDEP and Jardins-de-Napierville MRC representatives, an enterprise providing services to producers in the region, the *Féderation des producteurs maraîchers du Québec*, and an association promoting Québec's market garden products).

The qualitative data gathered were processed and analyzed using the approach and conceptual benchmarks set out in the strategic analysis of organizations (Crozier and Friedberg 1977; Friedberg 1988). We thus attempted to understand the individual strategies, restrictions, interests and strategic resources of the stakeholders we met with, with regard to various adaptation issues pertinent to the market garden sector. This helped us identify how the system of actors observed works in practice, to better understand power relationships, the interactions among actors and existing examples of cooperation, and to relate these observations to adaptation strategy implementation efforts.

6.5 Market Garden Production: Constraining Factors and Climate Change

6.5.1 Market Considerations Regarding Produce

Two key trends are presented by market garden producers and MAPAQ representatives with respect to market garden crops: the demands of food safety and cosmetic criteria emanating from national and international distributors. For the past few years, market gardeners have been under enormous pressure to meet the requirements of the Canada GAP program, a farm-based food safety program managed by the Canadian Horticultural Council. To respect these requirements, farmers have incurred increased production costs, and have also had to restructure daily activities affecting water management, including the quality of water required to irrigate vegetables. These increasing food safety demands are leading more and more producers to draw their water from the regional aquifer, which is of high quality.

Increasingly tough cosmetic criteria have had a greater impact on field losses and production costs, leading producers into a profound battle against insect pests and disease.

The study of the factors making adaptation to climate change more or less probable is taking place in a context in which multiple changes are already occurring, provoked by advances in other aspects of agricultural production. Climate change is one problem among many and limited resources often mean that farmers must deal with other, more pressing challenges first.

6.5.1.1 Irrigation

Studies carried out by the CEHQ conclude that by 2050, irrigation needs in the region will increase from 10 to 20 %. The regional aquifer will therefore be under greater pressure. A regional hydrogeological study revealed, however, that this aquifer has the capacity to supply all the irrigation needs of market garden production without affecting its refill rate (SPMSJV and Technorem 2008). The same study also forecast a 2 m drop in groundwater levels due to climate change. It is difficult to predict the consequences of this drop. In general, increasingly frequent extreme weather events, especially torrential rains and long periods of drought, are feared by producers and motivate them to set up flexible and reliable irrigation systems.

6.5.1.2 Waterway Maintenance and Flooding

Climate change will modify the precipitation regime, the frequency of extreme events and rainfall patterns throughout the year. According to the *Portrait du bassin versant de la rivière Châteauguay* produced by the SCABRIC, there is reason to be concerned that the problems in maintaining waterways will become more acute due to damage by increased erosion and more frequent sudden flooding.

The actors encountered who are not market gardeners have the impression that watercourse flooding events are occurring more frequently.

However, market gardeners are more of the opinion that flooding events vary from year to year and do not necessarily occur in the same places on the land and along the same waterways. Producers say that they must use all possible means to ensure that the waterways are maintained so that the water flow allows their drainage systems to operate efficiently to avoid flooding and to protect their crops.

6.5.1.3 Disease and Pest Control

Research carried out in 2011 by the MDDEFP in conjunction with an association of producers and professionals engaged in the research and development of good agricultural practices (the Prisme Consortium) confirms that a number of stakeholders have already considered promoting alternatives to pesticides to fight diseases and pests. However, although consumers fear the potentially negative effects of pesticides on their health, for the most part they still want cosmetically perfect and uniform fruit and vegetables which is difficult to attain without resorting to pesticides (CAAAQ 2008).

Producers are now seeing new pests, new or more virulent diseases, as well as a change in the dynamic of insects that are already present. This makes current means of control less effective or simply useless. Some of this is due to climate change, which, according to many producers, is causing extreme climate events of an intensity rarely seen before. For example, very heavy rainfalls create humid conditions and damage lettuce leaves, giving fungal diseases a foothold and making it too hazardous to go into the fields to apply treatments.

6.6 Relationships Among Stakeholders

We have been able to identify several concrete characteristics of the social network involved in market garden production in the sector under study.

6.6.1 The Relative Isolation of Market Gardeners

The representation of the interests of market gardeners is clearly fragmented and characterized by an absence of cohesion among them. They do not have a regional market garden organization. The *Fédération des producteurs maraîchers du Québec* appears not to have a good reputation, mainly because it has next to no power within the Union des producteurs agricoles (UPA), the central organization that brings together all agricultural producers in Québec.

Market gardeners also have a very strong entrepreneurial profile. They often sell the produce they grow directly to their distributors, negotiating the prices with them. Some belong to marketing cooperatives in order to sell specific types of vegetables. Several producers told us that the competition among them can sometimes be very fierce. They could be partners in growing one type of vegetable and competitors in the production of another. The successes and failures of certain practices are sometimes shared, and sometimes protected by producers who want to keep a competitive advantage over their neighbours. It appears that the cosmetic and health safety demands, as well as the difficulties related to the loss of fertile soil increases producers' stress levels and leads many to isolate themselves, because of what they interpret as a lack of understanding of their problems by many actors in the agricultural sector.

6.6.2 The Increasing Importance of Private Agronomy Enterprises

Through our work, we became aware of the presence of a key actor, systematically identified by respondents as having the closest and most trusted relationship with producers: the Prisme Consortium. It is a group composed of a screening network, a research company, a consultant service and an agro-environmental club. Many producers in the region use its services or have relationships with it. The development of close ties with private agronomists has occurred in a context in which the agronomic services provided by the MAPAQ have been drastically reduced and where advisory club membership has been constantly rising since 1997 (the MAPAQ has lost 30 % of its staff over the past 20 years).

For many producers, this enterprise is one of the main actors capable of playing a role in climate change adaptation. However, some producers are convinced that governmental institutions are not paying enough attention to it for there to be true cooperation among them. Many admit that they do not know where to go to look for the expertise and knowledge necessary to adapt to climate change because the information is dispersed between the MAPAQ, private agronomists and other organizations doing research on specific issues related to market garden production. The inadequate amount of networking among those with expertise adversely affects access to information that directly concerns adapting muck crops to climate change.

6.6.3 Uncertainty About the Activities of the Provincial Environment Department

Most producers have a negative view of the MDDEFP. Several mentioned its inability to ensure respect of its own regulations, its disconnection from producers' concerns, its tendency to unjustly identify producers as "major polluters" and its "police officer" attitude. For producers, the MDDEFP plays a restrictive role and is identified as being responsible for supervision and protection of water resources. They also perceive it as being unpredictable in how it imposes water charges or limits to water withdrawals. Because of this unpredictability, producers tend to turn their backs on the department, to limit their cooperation with it "outside of regulatory obligations" and to be averse to exchanging possibly useful information.

And yet, a civil servant from the MDDEFP told us that the department's priority is not to quantitatively limit producers with respect to irrigation and that it is not there to impede agricultural production, while explaining the provisions of the Groundwater Catchment Regulation and emphasizing the importance of protecting the quality of groundwater. Are farmers simply locked into a perception inherited from the past? The fact that the MDDEFP is not very active in the field and that it appears to be more reactive (to complaints) than proactive appears to contribute to reinforcing this perception.

6.6.4 Proximity to the MAPAQ

The relationship between producers and the MAPAQ is relatively good, but limited. The waning presence of the MAPAQ in the field has, of course, been noted. Farmers are not necessarily waiting for the MAPAQ to provide the technical means to deal with difficulties related to production, research and innovation in the market garden sector. It is seen more as a government body that defends the interests of agricultural producers, as an occasional source of subsidies and as being capable of uniting actors in the agricultural sector around the issues, including adapting to climate change, because of its expertise, knowledge and vast experience in the field.

6.6.5 The Watershed Organization: An Unknown Player

While our work initially dealt with adaptation to climate change and integrated water resource management by watershed, it appears clear that in the agricultural sector, the OBV is a fragile organization, more or less integrated into the network of actors observed. While a few producers mentioned the OBV and attested to the quality of its activities, many farmers only know it by name or not at all.

The voluntary approach to integrated water resource management by watershed is a long-term effort. While the government confirmed its importance to municipalities by adopting section 15 of the *Act to affirm the collective nature of water resources and provide for increased water resource protection* in 2009, requiring municipalities and MRCs to take water master plans into consideration when exercising their powers and duties, nothing has been done yet to formally rule on the role of OBVs in the agricultural sector.

6.7 From Organizational Reality to Adaptation

An understanding of the institutional and organizational characteristics of the market garden sector under study enables the identification of certain key elements in the sector's ability to adapt to changes in water conditions. The options considered are underpinned by a social reality characterized by management of agricultural land that remains very individualistic, a shifting network of governmental and private actors where resources are scarce, extreme pressure exerted by business imperatives, and the presence of an alternative resource to surface water (groundwater).

It is also important to keep in mind that agriculture in muck soil is affected by a serious problem of erosion that makes consideration of long-term objectives of little interest to producers. Adaptation to climate change therefore takes on a particular aspect: that of maintaining satisfactory production levels in the midterm, instead of ensuring that market gardening continues to be viable long into the future. Nevertheless, an understanding of the organizational phenomena identified reveals some potential comprehensive adaptation strategies.

6.7.1 Strategy 1: Link Individual and Collective Adaptation Measures

Market gardeners often opt for individual adaptation measures, on the scale of their own production: setting up drainage systems, cultivation in raised beds, leveling land, increasing drainage, planting windbreaks, ensuring green belts along rivers and other waterways, among others. These types of adaptation appear to be supported by the contractual relationship that producers have with service providers or advisory clubs.

Currently, the possibilities of investing in collective adaptation measures are few or insufficient. As noted by one of the producers interviewed, programs aimed at improving agricultural practices in the field are full of good intentions, but it may be better for the government and producers to invest massively to solve one specific problem once and for all, instead of spreading scarce resources over many programs that are each allocated small funding levels.

The Québec agricultural sector, through its organization, is involved in setting up mechanisms to link individual and collective efforts in matters of adaptation. Currently, this coordination does not appear to have a solid foundation, clearly identified by everyone. Yet this is necessary in order to pinpoint priority issues, allocate resources and find the best solutions.

6.7.2 Strategy 2: Foster Better Communication and Cooperation Among the Stakeholders

The issues under study—irrigation, watercourse maintenance, and disease and parasite control—involve a myriad of actors who sometimes have significant strategic resources invested in one issue and very little in another. Exchanges and cooperation among them are often concentrated on a single issue and negotiations are not carried out in an integrated manner. Producers are often the only stakeholders involved in all the issues and it is no surprise that there have often been communication problems among various government departments.

Even defining the problems and solutions related to climate change can be divisive. The need to implement collective adaptation measures runs up against an inability to reach a shared view of problems and solutions and to move forward with a holistic vision of market garden practices. And although the issues observed are all related to water resource management, not all of the OBVs are currently seen as being the cornerstone on which this cooperation could be built.

In addition, the interests of market garden producers are not satisfactorily represented before decision-makers. On the one hand, the MAPAQ, being less and less involved in the field, has limited ability to understand and to convey the issues specific to market garden producers, in the eyes of many. On the other hand, according to many market gardeners, the UPA does not faithfully represent their interests.

Therefore, not only is it difficult to reach a shared vision of the issues, because of a lack of adequate collaborative space, but the manner in which the positions of the market garden sector are communicated must be adjusted so that its specificities are not diluted within a too general conception of agriculture in Québec and the decisions taken at every level are consistent.

6.7.3 Strategy 3: Regulatory Renewal

For many, the institutional framework is an obstacle to the eventual implementation of an adaptation strategy. Modifications to it seem inevitable in order to improve the ability of the agricultural sector in general, and market gardening in particular, to adapt.

For example, the current framework regulating the maintenance of waterways is very restrictive and leads to delays and inconsistencies. Everyone agrees that regulatory reform is essential to ensure greater flexibility and to avoid the tensions that now exist between the needs of producers and the responsibilities of government departments, which are often incompatible with the urgency to act to ensure good flow in waterways. While the solution could involve informal agreements among the stakeholders, with the aim of reaching the objectives of the regulation in practice, this situation could lead to the practical imperatives being overestimated to the detriment of the objectives themselves.

While installing retention basins or controlling water flow are adaptations that have been considered, producers say that certain provisions of the Agricultural Operations Regulation (AOR) prevent them from deforesting their land, making planning for this type of infrastructure difficult. Similarly, as erosion affects muck soil, which is decreasing in area, and in the medium term these soils will no longer be exploitable because of erosion, the possibility of putting new land into agricultural production appears to be an option for maintaining market garden activities, but, again according to the understanding that producers have of the AOR, this option would be impossible.

On another subject, the trend towards constantly increasing demands with respect to food safety and cosmetic perfection can be incompatible with agricultural practices that have less of an environmental impact. Given the perception of market garden producers that the public will not tolerate the slightest presence of insects, the slightest trace of disease or the slightest physical deformation, producers must increase their energy consumption, sometimes their use of pesticides, their use of water and various resources (e.g. plastic gloves, multiple toilets in the fields and packaging). The institutional framework often reinforces these economic pressures and reduces farmers' room to manoeuvre which they need in order to adapt.

Finally, while the OBVs are supposed to be in charge of actions to adapt water use to climate changes, it is clear that the current institutional framework of voluntary membership does not guarantee recognition of the organization by the stakeholders and the results could be extremely variable from one sector to the other.

6.8 Conclusion

The adaptation of market garden agriculture to changes in hydrological and climatic conditions will ultimately mean modifications to agricultural practices and the establishment of infrastructure that will enable better water management. But these strategies are very dependent on the nature of the relationships that exist among local stakeholders, which are in turn affected by the institutional framework in place.

The need to adapt water use in the market garden sector to climate change are numerous, but the ability to adapt is undermined by the absence of a recognized space to cooperate and the splintering of issues within a complex and fragmented institutional framework.

Whether it is by building the capacities of the OBVs to act, by greater recognition of agronomy advisory clubs or by a renewal of the role of the State, which appears to be inimical to the current trend, the challenges stemming from the organizational context are numerous and require that an effective space to cooperate is put in place in order to:

- Gather and disseminate hydrological and climate information that is relevant to farmers;
- Ensure a definition of the issues and holistic solutions, both by linking the various issues involved in market garden production and by connecting them to other uses of water;
- Pool resources and expertise to implement adaptation;
- Permit concretely taking into account market garden sector issues consistent with the practical realities encountered.

However, the degradation of muck soils and the fact that some producers are aware that they are disappearing could pressure them into making short-term decisions with negative consequences in the long term. An additional challenge would be to connect the slow disappearance of organic soils in the production sector under study to the general objectives of adaptation for the water resource management sector.

Finally, our study highlights the importance of considering both institutional and organizational dimensions of collective action related to climate change adaptation. Social networks linked to the market garden sector in Quebec are clearly able to produce actions consequent upon a local appropriation of climate change challenges. Modifications to social components of adaptive capacity should require institutional innovations based on the understanding of actual social dynamics and eventually, on social learning processes.

References

Audet, G., Blackburn, F., Sullivan, A., & Lapointe, M.-C. (2010). *Portrait du bassin versant de la rivière Châteauguay*. Sainte-Martine: SCABRIC. 305 p.

CAAAQ (Commission sur l'avenir de l'agriculture et de l'agroalimentaire québécois) (2008). Agriculture et agroalimentaire: assurer et bâtir l'avenir—Propositions pour une agriculture durable et en santé. Final report. Montréal: Quebec Government, 274 p.

Côté, M. J., Lachance, Y., Lamontagne, C., Nastev, M., Plamondon, R., & Roy, N. (2006). *Atlas du bassin versant de la rivière Châteauguay*. Québec: Ministère du Développement durable, de l'Environnement et des Parcs. 64 p.

Crozier, M., & Friedberg, E. (1977). *L'acteur et le système*. Paris: Éditions du Seuil. 436 p.

Cyr, J.-F., Turcotte, R., Sévigny-Côté, L., & Roussel, D. (2012). *Rapport préliminaire: Évaluation des impacts des changements climatiques et des besoins d'adaptation liés à l'irrigation pour un bassin agricole du Québec*. Québec: Centre d'Expertise Hydrique du Québec. 23 p.

FPQM (Fédération des producteurs maraîchers du Québec) (2006). Inventaire des problématiques environnementales spécifiques au secteur maraîcher québécois, Final report, Longueuil: Conseil pour le développement de l'agriculture au Québec, 80 p.

Friedberg, E. (1988). L'analyse sociologique des organisations. *J Pour, 28*, 104–121.

Lépine, Y. (1973). Forces sociales et forces de production dans les terres noires de Napierville-Châteauguay. *Cah Géog Québec, 42*(17), 389–414.

Milot, N., Lepage, L., Choquette, A., Lafitte, J., Larivière, V., Larocque, J., Lefebvre, B., Marquet V., & Veret, A. (2013). Adaptation aux changements climatiques et gestion intégrée de l'eau par bassin versant au Québec: une analyse sociopolitique des défis et des opportunités. Réalisé dans le cadre du Plan d'action 2006–2012 sur les changements climatiques du Gouvernement du Québec, Montreal: Institut des sciences de l'environnement – UQÀM, 324 p.

Ostrom, E. (2005). *Understanding institutional diversity*. Princeton: Princeton University Press. 355 p.

Ouranos. (2010). *Savoir s'adapter aux changements climatiques*. Montréal: Consortium Ouranos. 128 p.

Papineau, F., Gallichand, J., Broughton R. S., & Laverdure, G. (1993). Analyse pour la gestion des ressources hydriques à des fins agricoles dans le bassin versant de la rivière l'Acadie. Entente auxiliaire Canada-Québec sur la conservation des sols en milieu agricole, Salaberry-de-Valleyfield: UPA Saint-Jean-Valleyfield.

SPMSJV (Syndicat des producteurs maraîchers de Saint-Jean-Valleyfield) and Technorem Inc. (2008). "Étude hydrogéologique régionale dans la zone de production maraîchère des bassins versants des rivières Norton, Esturgeon, Saint-Pierre et de la Tortue, Montérégie". Project 5074 du Conseil pour le développement de l'agriculture du Québec (CDAQ), 1006 p.

Annie Choquette obtained her Master degree in Environmental Sciences from l'UQÀM (Université du Québec à Montréal) in 2012. The opportunities and barriers for adaptation to climate change in Norton's Creek's watershed was the subject of her master's thesis. Annie Choquette is now working for Chamard Stratégies Environnementales, pursuing her interest for sustainable development in municipal management.

Nicolas Milot completed his Ph.D. in environmental sciences in 2009 at the Université du Québec à Montréal (UQAM). His research focuses on the implementation of participative governance for natural resources, climate change adaptation and new forms of environmental policies. He is the coordinator of the Regional Round Table for the integrated management of the St. Lawrence River in Montreal area and acts as Adjunct Teacher at the Institut des sciences de l'environnement – UQAM.

Laurent Lepage obtained his doctorate from the Institut d'Études Politiques de Paris. He is a Full Professor at the Institute of Environmental Sciences of the Université du Québec à Montréal (UQAM). His research, in Canada and on the international scene, focuses on the implementation of environmental policies and on social dynamics. His recently published work examins the link between science, public decision-making and local communities in the new area of integrated management and climate change adaptation.

Chapter 7
Citizen Involvement and Volunteering Along the Acadian Coastline: Challenges for Integrated Management and Adaptation in the Context of Climate Change

Omer Chouinard

Abstract This chapter deals with the question of how participative research action processes can reinforce the capacities and public policies for coastal communities threatened by extreme climate-related events. It deals with the problem of adaptation at the community level and brings new perspectives to the domain of research on adaptation to climate change. Coastal communities in this region, which have been faced with extreme events caused by climate change and variability (giving rise to impacts in terms of erosion and flooding), are confronted with three choices: coping, protection or withdrawal. Given the urgency of the situation in the Acadian coastal communities in New Brunswick, the challenge for researchers was to reinforce the capacities of these communities in order to help them to adapt better. Research action was used, involving many different approaches to helping build capacity, while at the same time respecting the independence of the actors ... citizens, associations, local and provincial actors. The researchers involved thus contributed to reinforcing local governance and to identifying appropriate measures and establishing priorities that respected a broader social justice. The researchers thus became involved in a process of co-construction of adaptation plans through a participative research action process. The challenges encountered and the solutions developed are presented in such a way that they can be transferred and used in other domains necessitating adaptation to climate change and variability, such as farming and other types of rural communities.

Keywords Climate change • Adaptation • Coastal community • Local governance • Participatory research • Public policies

---

O. Chouinard (✉)
Department of Sociology and Environmental Studies, University of Moncton, 18 Ave Antonine-Maillet, B-007 Rémi-Rossignol, Moncton E1A3E9, NB, Canada
e-mail: omer.chouinard@umoncton.ca

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_7

7.1 Introduction and Context

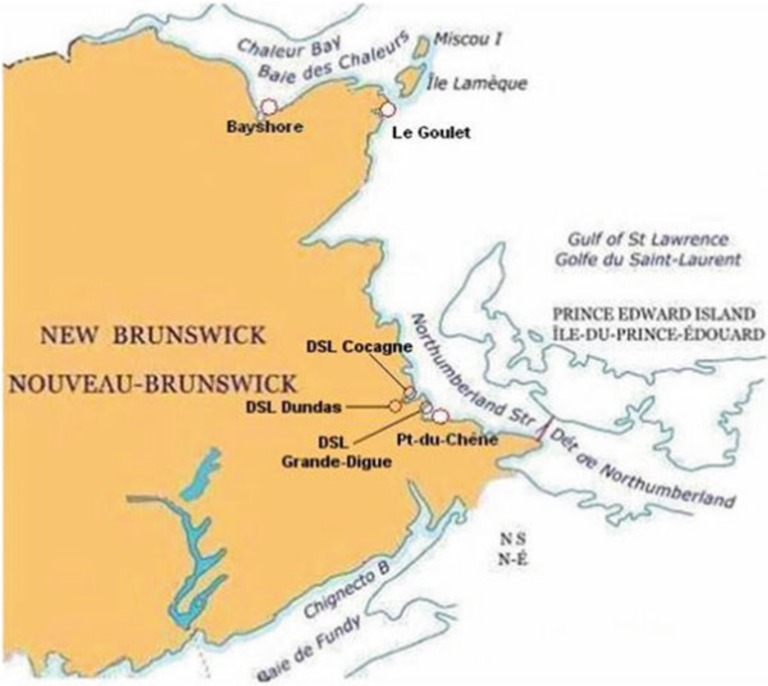
According to IPCC's Fifth Assessment Report, Summary for Policymakers (2013) states that Climate Changes are caused by anthropogenic factors. This statement confirms and reinforces the information from other IPCC Reports over the past 25 years. "It is *extremely likely* that more than half of the observed increase in global average surface temperature, from 1951 to 2010, was caused by anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together." (IPCC 2013: 12). Due to rising sea levels and climate change, coastal communities in the Gulf of Saint-Lawrence and Atlantic Canada are facing loss of their personal properties as well as local and institutional infrastructures (Daigle 2006; Lemmen et al. 2008). This information, both on a global and regional scale, stimulated representatives of local communities to ask researchers from the Université de Moncton to accompany them in their adaptation to climate change. We have used Participatory Action Research (PAR) with communities facing rising sea levels and flooding to develop an Action Plan (Chouinard et al. 2006, 2008; Kostrzewa et al. 2008; Chouinard et al. 2011; Plante et al. 2011; Chouinard and Martin 2012).

This chapter is founded on the perspective of social economy and participatory action research. It aims to provide support for decision-making in adaptation to climate change, which have had impacts such as erosion and rising sea levels for coastal Acadian communities in New Brunswick. This area represents an ecosystem of nearly 4,000 km of coastline and estuaries that span from the borders of Quebec, Chaleur Bay on the north side, the Gulf of St. Lawrence on the east side, and Northumberland Strait to Green Bay on the border of Nova Scotia's southeast side (Fig. 7.1).

Many residents of this territory's coastal areas are regularly faced with erosion and flooding problems. This contribution, on adaptation to climate change in coastal areas, emanates from a collaborative project we have been conducting since 2002. The particular feature of this project is that some coastal communities along the Acadian Coastline have requested assistance to develop effective planning in a context of solidarity and support, so that people can plan and anticipate the impacts regarding coastal hazards caused by the phenomenon of climate change. In this chapter we wish to demonstrate how we have helped fill this gap by co-constructing (Vaillancourt 2011) adaptation tools.

This summary of our work is part of our collaboration with the New Brunswick departments of Environment and Local Government and Natural Resources, and especially with the communities of Le Goulet, Pointe-du-Chêne, Carron Point and Cocagne/Grande-Digue,[1] with whom we are associated in a research partnership (Fontan 2011). We have found that the general problem of adaptation in coastal areas varies considerably from one place to another, depending on the type of social

[1] We are greatly indebted to the CCC-Challenges of coastal communities (2010–2015) and Social Economy and Sustainability in Atlantic Canada (2005–2010) for funding this work.



Source: The coast of New Brunswick, DGT/Université de Moncton, 2012

Fig. 7.1 New Brunswick's entire coastal territory and water level of the Acadian coast

organization and leadership. This also implies that adaptation options vary. It was therefore important to examine each of the communities in light of a thorough and comprehensive approach.

We designed, in partnership with local communities, an approach to commitment considered on the basis of social economy and the methodology of participatory action research (PAR) (Kindon 2010). We believe this would allow our communities to deliberate in order to better ensure planning and implementation of selected measures to adapt to climate change. The results of the various studies with the CCC-CURA (Coastal Communities Challenges Community-University Research Alliance), CURA for Social Economy in Atlantic Canada have shown us the importance of the needs of diverse communities with respect to environmental governance and dissemination of information concerning the phenomenon of climate change at the local and international levels.

This chapter is the result of several case studies (Roy 2009; Yin 2009) on adaptation to climate change on the Acadian Coastline. The introduction as we have seen, places the Acadian coast of the province of New Brunswick and the Gulf of St. Lawrence in the context of Atlantic Canada. We then review the theory and concepts used, as well as the research methodology adopted. We then analyze the support of researchers in the various stages of research with the selected communities. Finally, we report on what has been learned from the research with communities and we conclude on prospects for the future.

7.2 Concepts and Methods

As previously stated (Chouinard and Martin 2012: 82–94), social economy organizations are rooted in local communities and are normally democratic and participatory in nature. Therefore research in the field of social economy warrants the use of participatory action research (PAR) approaches. Such approaches tend to refer to new governance where local stakeholders are part of the decision-making process and where resource management is rooted in local communities. PAR emphasizes not only the participation of stakeholders, but also their co-ownership of the research. This means that research design, goals and objectives and methods are decided amongst partners, and that research outcomes are shared and more readily available to promote social benefits.

There is a natural connectivity between PAR and the field of social economy (Bouchard 2011; Kindon 2010; Pain 2010). The ties between social economy and the so-called ecosystem approach are less often discussed. The ecosystem approach as integrated management has evolved from the notion of sustainable development, and can thus be defined as "a holistic process for integrating and delivering, in a balanced way, the three objectives of the Convention of Biological Diversity: conservation and sustainable use of biodiversity and equitable sharing of the benefits" (Maltby 2000: 1). The ecosystem approach shares many of the social economy's principles because of its focus on sustainable management of resources for the common good and for future generations.

Many social economy groups are forming the backbone of sustainable community initiatives, since their objectives and focus are of benefit to society and the community ownership of common resources. These associations and their extended web of partnerships in the smaller communities help strengthen what Gunderson and Holling (2002) refer to as adaptive capacity. Adaptive capacity is defined as the capacity of ecological and human social systems to adapt when the existing system is changing. It is related to the sum of capacities, resources and institutions of a region that allow it to set in place efficient adaptation measures (IPCC 2007).

We argue that social economy associations are an integral part of community resilience in facing new and changing systems, such as the case study discussed in this chapter.

At the local level, a good number of rural communities along the Acadian Coastline of northern and eastern New Brunswick are devoid of municipalities. Thirty-five percent of communities are made up of local service districts (LSD) and have no elected bodies with whom they may deliberate and propose public policies for their territory. In addition, some municipalities are communities of less than 2,000 and even less than 1,000. Thus they do not have the resources and the human capital to develop appropriate public policies. The researchers called on to intervene in these communities have played a governance role in the coordination with various departments and local municipalities for the purpose of proposing public policies.

7.3 A Case Study Along the Acadian Coastline (2002–2013)

Note first that the coastal ecosystem on which we report here includes the upstream watershed (Peyron and Blanchard 2012) and the ocean of the downstream coastal zone to a depth of 30 m (Lanteigne 2010). In addition to the breeding of salmon and pelagic species upstream, we find the habitats of commercial fisheries such as lobster and herring downstream. In addition, aquaculture, forestry, agriculture and tourism play a major role in the activities of coastal zone waters (Bastien-Daigle et al. 2011; Chadwick 2011; Vanderlinden and Friolet 2011).

Impacts from climate change and rising sea levels are particularly important for coastal communities where flooding and erosion are predicted to become more severe (Chouinard and Martin 2012). In Canada, certain parts of the coastline are particularly vulnerable to storm surges and rising sea levels (IPCC 2007). This is true for some parts of the coast in the province of New Brunswick and also in Newfoundland and Labrador (Daigle 2006). Previous studies conducted in South Eastern New Brunswick confirm that although some adaptation is occurring, there is a definite lack of government resources and direction to promote a cost-effective and sustainable response (Auditeur Général du Canada 2010; Chouinard et al. 2006, 2008, 2009, 2011; Plante et al. 2011; Daigle 2006; Delusca et al. 2004). As well, Atlantic Canada's experience shows that adaptation does not rely solely on technical or engineering solutions. Coordination and cooperation between stakeholders in the design and implementation of a common strategy for adaptation, inevitably linked to governance, seem necessary to incorporate the complexity of the climate change phenomenon, rising sea level and impact on the coastal area (Beuret and Pannanger 2002).

Since 2003, researchers from l'Université de Moncton have attempted to work with municipalities and other local stakeholders, in order to help build community adaptive capacity through a community engagement process. The engagement process used by means of participatory action research (Poitras et al. 2003; Ballard 2005; Gustavsen 2003; Attwater and Derry 2005) consists of three parts. First, researchers gathered local knowledge and perceptions from a number of residents from the coastal zone on climate change, local impacts and adaptation by interviews (Savoie-Zajc 2009). Second, researchers from different fields participated in the presentations to community committee groups, in order to bring scientific knowledge. Scientific knowledge, combined with local knowledge gathered in step one, provided a broader view of the issue at hand. The third part of the process aimed at merging all of the stakeholders, leading to the realization of an operational plan for adaptation to climate change impacts and rising sea levels. This was implemented through focus group meetings (Geoffrion 2009) with community stakeholders, including local associations and local leaders. The final outcome of the process was the writing of a community adaptation plan in which participants agreed on priorities for future adaptation. This community engagement process was conducted in four distinct coastal communities. Pointe-du-Chêne, a non-incorporated community, a Local Service District (LSD) is located 25 km from Moncton, NB, with a summer population of 3,000, most of who do not live there year round. Located on a small peninsula, this community is very susceptible to flooding and coastal erosion. The second community is the town of Le Goulet, a municipal township of less than 900 residents, located in the Acadian Peninsula. In recent years, this community has seen its coastal dune diminished by erosion and has witnessed some flooding of houses and streets (Natural Resources Canada 2011). The community of Bayshore Drive is a small agglomeration of 60 residences located on a coastal sandspit within the limits of the city of Bathurst (population 12,000). Residents have been very concerned both about accelerated erosion and the random construction of erosion structures since the year 2000. The forth one, Cocagne/Grande-Digue, is a non-incorporated, Local Service District (LSD) located 30 km from Moncton. The population is 4,727. This LSD has lost roads and public infrastructures like wharves in 2000 and in 2010. As well, flooding has covered roads and isolated some agglomerations for 3 days.

The process of adaptation to climate change in four different coastal communities shows some evolution of perceptions and has helped communities to plan for the future. For example, in Pointe-du-Chêne, the exercise was valuable to participants mostly because it offered a means to validate and consolidate options already identified by community leaders. The main option consists of raising the bridge that constitutes principal access to the community since it is often flooded during storm surges. This option has since been presented to provincial government authorities with success.

In Le Goulet, the process has brought about an important change in residents' options for adaptation. Participants have shifted their view from a 5-million-dollar rock wall of the existing sand dune that shelters the community, to a more prudent approach consisting of moving the most vulnerable low-lying houses away from the shore. This idea has not yet been secured.

In Bayshore, group discussions focused on the need to create a municipal bylaw that would provide harmonization of erosion control structures. However, the municipality is fearful of imposing such a bylaw, because of its legal implications and responsibility demands. The community group also needs to work at increasing the awareness of coastal residents regarding approaches to erosion control and the need for sustainable adaptation scenarios. An educational booklet has been produced for this purpose.

In Cocagne/Grande-Digue, the process has given rise to two different options. One is to increase awareness for new buildings along the coastline. The other is to raise the awareness of populations along the watershed about the increase of sedimentation in the river, caused by extreme events and roads in the forest that are in bad conditions. An educational booklet describing these two options is now in production.

The process also revealed some difficulties in implementing different measures for adaptation. Lack of resources and lack of local ownership in terms of decision-making were often cited by participants as important obstacles for achieving adaptation. Although it is at the local government level that ownership and stewardship of development for more sustainable futures are more likely to emerge (Beatly et al. 2002), the structures for governance at this level are not always in place to facilitate action. In fact, many rural areas in the province of New Brunswick, such as Pointe-du-Chêne and Cocagne/Grande-Digue, are not represented by municipal bodies, but rather by Local Service Districts (LSD) that have little power or financial means. We believe this is a major obstacle in the promotion of better local stewardship and control of adaptation, and it points to the importance of involvement of associations and other social economy participants. Our research has shown that the presence of locally-based associations and volunteer organizations can be critical in driving the engagement initiatives toward sustainable solutions, especially in smaller non-incorporated communities.

The process has resulted in a great deal of interest in some communities, since it offered a different approach to the current governance, with the coming-together of community members, social economy groups, regional civil servants and researchers from the scientific community. The process has also enabled researchers to identify conflicting values that are present in communities. In Bayshore, for example, many residents were afraid of possible losses to their property value if "negative" views of living in the area resulted from communication material. This shows the difficulty of collective long-term benefits over individual short-term benefits.

7.4 Discussion and Conclusion

Participatory action research, on which these four cases of social economy research were based, is essentially a deliberation process aimed at enhancing community engagement and mobilization. In research dealing with adaptation of local communities to climate change, it is apparent that greater support is needed to help communities develop action plans that will allow better security and resilience in the future. We believe that the fusion of rural communities to form a minimal population of 14,000 is necessary to attain the critical mass for community deliberation and support for actions. Democratic deliberation is not possible without citizens' access to human and financial resources and technical expertise that will enable wise decision-making: public sector services also play a critical role in supporting such a process (Auditeur général du Canada 2010; Lemmen et al. 2008; Daigle 2006).

Participatory Action Research was a learning process for the associations, municipalities and non-incorporated LSD's and researchers involved. We have gained a deeper knowledge of how to apply conflict resolutions in order to develop adaptation plans and how to develop municipal bylaws and policies to ensure adaptation for general interest.

We believe that the social economy approach and partnership approach along the Acadian coastline were strengthened by experiences in adaptation to climate change led by a community. A common thread that was visible through all four research cases is that work had been initiated by communities on community adaptation, by pooling of the few local resources communities have at their disposal. Local communities like Pointe-du-Chêne had already started community meetings and had put together an emergency shelter for extreme flood events. Also, provincial government has built a new bridge for evacuation during extreme events. Cocagne/Grande-Digue had established a connection with emergency measures to provide local food and care to the people. It is apparent that the coming-together of different social economy associations and other local groups is essential in developing appropriate and locally-based public actions. However, the role of the state (provincial and federal) in supporting and encouraging these initiatives and formulating appropriate policy remains critical for the success in developing sustainable communities for the future.

The method of Participatory Action Research, inspired by the social economy, has been used in various research projects related to natural resources over the past 10 years, both in Canada and in the Atlantic Provinces (Bouchard 2013; Mook et al. 2012; Novkovic and Brown 2012). Of particular note are some research projects of graduate students in the Masters of Environmental Studies program at the Université de Moncton: first, research on the link between rural producers and urban consumers in local agriculture with the Really Local Harvest cooperative, in Southeastern New Brunswick (Michaud 2010); then, the one on the socio-economic importance of ecosystem services of an oyster reef in the Bay of Caraquet (Cousineau 2011) or again, on the perception of social economy groups regarding the exploitation of shale gas in Kent County, New Brunswick (Bell 2013). As well, there is our research assistance with credit, food and fishing coops on Lamèque Island in the Acadian Peninsula of New Brunswick (Chouinard et al. 2010).

This approach promotes ownership of the results for action by local municipalities. It allows for community capacity building, and deliberation on issues of natural resource management, notably regarding the future of rural communities. Undertaken properly, this research tool contributes as much to social justice in the communities as it does to legitimize social research rooted in them.

References

Attwater, R., & Derry, C. (2005). Engaging communities of practice for risk communication in the Hawkesbury water recycling scheme. *Action Research, 3*(2), 193–209.

Auditeur Général du Canada. (2010). Letter addressed to one author of this paper concerning the importance to Federal Government to answer to the request of citizen about adaptation, August 18th, 2010.

Ballard, D. (2005). Using learning processess to promote change for sustainable development. *Action Research, 3*(2), 135–156.

Bastien-Daigle, S., Vanderlinden, J.-P., & Chouinard, O. (2011). Les perceptions de la mise en oeuvre d'une gestion intégrée en zone côtiere au Canada atlantique. In O. Chouinard, J. Baztan, & J.-P. Vanderlinden. *Zones côtières et changement climatique : le défi de la gestion intégrée* (chap. 4, pp. 78–97). Québec: Les Presses de l'Université du Québec.

Beatley, T. D., Brewer, D. J., & Schwab, A. K. (2002). *An introduction to coastal zone management* (2nd ed.). Washington, DC: Island Press.

Bell, T. (2013). *Perception de l'extraction du gaz de schiste par les organismes d'économie sociale du comté de Kent (sud-est) du Nouveau-Brunswick*. Thèse de Maîtrise, Programme de Maîtrise en études de l'environnement. Faculté des études supérieures et de la recherche, Université de Moncton, 113 pages.

Beuret, J.-E., & Pennanguer, S. (2002). Quand les citoyens modèlent l'action publique: La gouvernance des espaces littoraux. *Revue Pour, 174*, 171–178.

Bouchard, M. J. (2011). *L'Économie sociales vecteur d'innovation: l'expérience du Québec* (255 p). Québec: Les Presses de l'Université du Québec.

Bouchard, M. J. (Ed.). (2013). *Innovation and the social economy: The Québec experience* (280 p.). Université of Toronto Press.

Chadwick, M. (2011). Préface. In O. Chouinard, J. Baztan, & J.-P. Vanderlinden (Eds.), *Zones côtières et changement climatique : Le défi de la gestion intégrée* (pp. VII–XII). Les Presses de l'Université du Québec, Québec.

Chouinard, O., & Martin, G. (2012). Community management and community resources. In S. Novkovic & L. Brown (Eds.), *Social economy, communities, economies and solidarity in Atlantic Canada* (pp. 82–94). Sydney: Cape Breton University Press.

Chouinard, O., Plante, S., & Martin, G. (2006). Engagement des communautés face au changement climatique: une expérience de gestion intégrée à Le Goulet et à Pointe-du-Chêne du Nouveau-Brunswick. *VertigO – la revue électronique en science de l'environnement* (On line), *7*(3). http://vertigo.revues.org./1912; doi:10.4000/vertigo.1912.

Chouinard, O., Plante, S., & Martin, G. (2008). The community engagement process: A governance approach in adaptation to coastal erosion and flooding in Atlantic Canada. *Canadian Journal of Regional Science, XXXI*(3), 507–520.

Chouinard, O., Martin, G., & Plante, S. (2009). Renforcement des capacités des collectivités côtières dans la livraison de services aux citoyens face à la hausse du niveau marin: une approche d'économie sociale. *Marché et Organisations, IX*, 107–129.

Chouinard, O., Leclerc, A., Beaudin, M., Martin, G., & Donouvou-Vinagbe, P. (2010). Contribution de la coopération, de l'économie sociale et des entreprises collectives dans le développement territorial des Îles Lamèque et Miscou en Acadie du Nouveau-Brunswick. *Revue de l'Université de Moncton, 41*(1), 49–82.

Chouinard, O., Baztan, J., & Vanderlinden, J.-P. (Eds.). (2011). *Zones côtières et changement climatique : Le défi de la gestion intégrée*. Québec: Les Presses de l'Université du Québec.

Cousineau, M. (2011). *L'importance socio-économique des services écologiques d'un récif d'huîtres dans la baie de Caraquet*. Thèse de Maîtrise, Programme de la MÉE. Faculté des études supérieures et de la recherche, Université de Moncton, 116 pages.

Daigle, R. (Ed.). (2006). *Impacts of sea level rise and climate change on the coastal zone of Southeastern New Brunswick* (611 p.). Environment Canada. ISBN 0-662-72412-7.

Délusca, K., Tremblay, M., & Chouinard, O. (2004). Climate change, perception and perspectives: Case study of coastal communities in South-Eastern Part of New Brunswick. Technical Report. *Université de Moncton*.

Fontan, J. M. (2011). La recherche partenariale en économie sociale: l'expérience québécoise. In M. J. Bouchard (Ed.), *L'économie sociale vecteur d'innovation: l'expérience du Québec, chap. 2,* (pp. 63–88). Québec: Les Presses de l'Université du Québec.

Geoffrion, P. (2009). Le groupe de discussion. In B. Gauthier (Ed.), *Recherche sociale. De la problématique à la collecte de données* (5è édition, chap. 15, pp. 391–414). Québec: Les Presses de l'Université du Québec.

Gunderson, L., & Holling, C. S. (Eds.). (2002). *Panarchy: Understanding transformations in human and natural systems* (507 p.). Island Press.

Gustavsen, B. (2003). New forms of knowledge production and the role of action research. *Action Research, 1*(2), 153–164.

IPCC. (2007). In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hansen (Eds.), *Contribution of Working Group II to the Forrth Assessment Report of the International Panel on Climate Change*. Cambridge: Cambridge University Press.

IPCC. (2013). Working group I contribution to the IPCC Fifth Assessment Report Climate Change 2013. In *The physical science basis, summary for policymakers* (36 p).

Kindon, S. (2010). Participation. In S. Smith, R. Pain, S. A. Marston, & J. P. Jones III. *The Sage handbook in social geographies* (chap., 23, pp. 517–545). London: Sage Publications.

Kostrzewa, C., Émond, P., Chouinard, O., Gauvin, J., Brideau, M., et Langis, M. (2008). *Dynamique communautaire et développement durable : les expériences des associations canadiennes du sud du Golfe du Saint-Laurent* (2) No. 7 sous la direction de Zaoual, H. Marché et organisations. Développement durable des territoires : économie sociale, environnement et innovation (pp. 205–232). Paris: Éditions L'Harmattan. ISBN 978-2-296-06719-9.

Lanteigne, M. (2010). Workshop to define the coastal zone and data compilation for Ecologically and Biologically Significant Areas (EBSA) assessment, December 14 and 15, 2010. Department of Fisheries and Oceans, Moncton, Gulf Center. On line: http://www.dfo-mpo.gc.ca/csas-sccs/Schedule-Horraire/2010/12/12_14-15-eng.html

Lemmen, D. S., Warren, F. J., Lacroix, J., & Bush, E. (Eds.). (2008). *From impacts to adaptation: Canada in changing climate 2007* (Chap. 4, 448 p.). Ontario: Government of Canada. Available on line: Adaptation2007.nrcan.gc.ca.

Maltby, E. (2000). Ecosystem approach: From principle to practice. *Ecosystem Service and Sustainable Watershed Management in North China International Conference*, Beijing, P.R. China, http://www.biotechnology.uni-koeln.de/inco2-dev/common/contribs/18_maltb.pdf

Michaud, D. (2010). *Contribution d'une entreprise d'économie sociale agricole à l'alimentation de proximité et à la sécurité alimentaire selon les principes du développement durable: Le cas de la Récolte de chez-nous dans le sud-est du N.-B*. Thèse de Maîtrise, Programme de la Maîtrise en étude de l'environnement, Université de Moncton. 85 pages.

Mook, L., Quarter, J., & Ryan, S. (Eds.). (2012). *Business with a difference: Balancing the social and the economic*. Toronto: University of Toronto Press.

Natural Resources Canada. (2007). *Climate change impacts and adaptation: A Canadian perspective*, Ottawa. Available on line http://www.nrcan.gc.ca/earth-sciences/products-services/publications/climate-change/climate-change-impacts-adaptation/356

Natural Resources Canada. (2011). Le Goulet's climate change adaptation plan, planned relocation as an option to address Sea-Level Rise, On line visited September 29, 2013.

Novkovic, S., & Brown, L. (2012). *Social economy: Communities, economics and solidarity in Atlantic Canada* (260 p.). Sydney: Cape Breton University Press.

Pain, R. (2010). Introduction: Doing social geographies. In S. Smith, R. Pain, M. A. Marston, & J. P. Jones III (Eds.), *The Sage handbook in social geographies* (Section 5, pp. 515–516), London: Sage Publications.

Peyron, D., & Blanchard, G. (2012). « La gestion durable des zones côtières et marine : nouveau discours, nouvelles durabilités, nouvelles frontières », *VertigO – la revue électronique en sciences de l'environnement* [En ligne], Hors-série 9 | Juillet 2011, mis en ligne le 12 août 2011, consulté le 15 octobre 2013. http://vertigo.revues.org/11043

Plante, S., Chouinard, O., & Martin, G. (2011). Gouvernance participative par l'engagement citoyen à l'heure des changements climatiques : Études de cas à Le Goulet, Pointe-du-Chêne et Bayshore Drive (Nouveau-Brunswick) dans. *Territoire en mouvement, 11*, 33–49.

Poitras, J., Bowen, R., & Wiggin, J. (2003). Challenges to the use of consensus building in integrated coastal management. *Ocean and Coastal Management, 46*, 391–405.

Roy, S. N. (2009). L'étude de cas. In B. Gauthier (Ed.), *Recherche sociale : de la problématique à la collecte de données* (5è éd, chap 8, pp. 199–226). Québec: Les Presses de l'Université du Québec.

Savoie-Zjac, L. (2009). L'entrevue semi-dirigée. In B. Gauthier (Ed.) *Recherche sociale. De la problématique à la collecte de données* (chap. 13, pp. 337–360). Québec: Les Presses de l'Université du Québec.

Vaillancourt, Y. (2011). La coconstruction de politiques publiques: l'apport de l'économie sociale. In M. J. Bouchard (Ed.), *L'économie sociale vecteur d'innovation: l'expérience du Québec*, chap. 4 (pp. 115–143). Québec: Les Presses de l'Université du Québec.

Vanderlinden, J. P. et Friolet, R. (2011). La gestion intégrée de la zone côtière dans un contexte aquacole : l'expérience de la baie de Caraquet. In O. Chouinard, J. Baztan, et J.-P. Vanderlinden. *Zônes côtières et changement climatique : le défi de la gestion intégrée* (chap. 3, pp. 57–78). Les Presses de l'Université du Québec.

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Thousands Oaks: Sage Publications.

Omer Chouinard holds a Ph.D. in Sociology (UQAM, 1992). He is professor in the Department of Sociology and Master's Program in Environmental Studies at the University of Moncton. He directed the program from 1999 to 2007. He has worked 40 years in the areas of sustainable development, community involvement, natural resource management, outreach and education, the environment and building community capacity to take care of their environment. His principal current research interests are in the domain of coastal community adaptation to climate change, and he has published widely in this domain.

Chapter 8
The Contribution of Agronomic Research to Innovation: The Experience of INRA-SAD in France

Christophe-Toussaint Soulard and Jean-Marc Meynard

Abstract Faced with the crises and challenges associated with global change, innovation has been put forward as the solution sine qua none to construct adaptation strategies for agriculture. However, while various technical solutions have been discovered by farmers and researchers, and while the principles of sustainable development have been put forward in public policy, the implementation of a sustainable agricultural alternative has been slow in becoming established. This perspective demands that agronomic research become more innovative. In France, the Sciences for Action and Development (Sciences pour l'Action et le Développement (SAD)) division of the French National Institute for Agricultural Research (Institut National de la Recherche Agronomique (INRA)) was created in 1979 to better understand the reasons for the resistance of farmers to the adoption of innovations associated with the dominant productivist model. Using a systemic approach, the research in the SAD division revealed the diversity of innovation processes by which farmers adapted to change. This research also gave rise to the development of certain technical solutions, based on the principles of agro-ecology and territorial innovation, and which appeared capable of helping a diversity of agricultural systems to reorient themselves towards greater sustainability. During this research, the principle of co-construction of solutions involving researchers and practitioners became affirmed. Faced with the challenges of climate change, these researches need a more prospective approaches.

Keywords Agroecology • Territory • Action-research • Farming system • Design

---

C.-T. Soulard (✉)
French Institute for Agricultural Research (INRA), Montpellier, France
e-mail: soulard@supagro.inra.fr

J.-M. Meynard
French Institute for Agricultural Research (INRA), Paris, France
e-mail: meynard@grignon.inra.fr

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_8

8.1 Introduction

Faced with the crises and challenges associated with global change, innovation has been put forward as the solution sine qua none to construct adaptation strategies for agriculture. However, while various technical solutions have been developed by farmers and researchers, and while the principles of sustainable development have been integrated into public policy, the implementation of the sustainable agricultural alternative has been slow in becoming established. This perspective demands that agricultural research becomes more innovative. How do we move towards greater sustainability? This challenge requires the renewal of innovation systems in agriculture and food (Coudel et al. 2013).

In France, the Sciences for Action and Development (SAD) division of the French National Institute for Agricultural Research (INRA) was created in 1979 to understand the reasons for the resistance of farmers to the adoption of technical innovations. Using a farming systems approach (Darnhofer et al. 2012) and focusing on agricultural practices analysis (Brossier et al. 1993), the research at SAD revealed the diversity of innovation processes by which farmers adapted to change. This research also gave rise to the development of certain technical solutions, based on the principles of agroecology (Wezel et al. 2009), and which appeared capable of helping a diversity of agricultural systems and rural areas to reorient themselves towards greater sustainability (Meynard 2013).

But the transitions towards sustainable agriculture systems do not happen automatically. The case of France, the first agricultural producer country in Europe,[1] illustrates this problem. The agro-industrial production model which has been dominant since the 1960s, has achieved high levels of agricultural production, abundant food and low prices. But it has also given rise to negative effects on the environment and created a climate of public concern following various food scandals. This model is disputed today: an unprecedented innovation effort is needed to reconcile economic and ecological performances.

This chapter aims to explain how research can contribute to innovation in agriculture in this new context. It is based on a diagnosis of the relationships forged between research and agricultural development in France. This analysis shows that while the current environment promotes innovation in the context of sustainable development, innovative sustainable forms of agriculture are having a hard time to be recognized and established. To solve this problem, it is necessary to design innovations that allow for a plurality of development models and a variety of actors able to boost innovation. We then explore two approaches that can contribute to innovation: agroecology and relocalisation of agriculture. Based on our analyses of these approaches, we explore how the climate change phenomenon can contribute to agricultural innovation, including prospection, or looking forwards, and learning.

---

[1] In 2010, the value of France's agricultural production was 66 billion euros, representing 18.6 % of the agricultural value of the EU and its 27 States. Source: Grafagri (2011): http://agreste.agriculture.gouv.fr/IMG/pdf_Gaf11p046.pdf

8.2 The Issue of Agricultural Innovation in France

8.2.1 Innovations and Agricultural Development: National Trends

In France, the relationships between public agronomic research and agricultural development, driven by the industry and the state, have always been close. However, these relationships have undergone transformations over time that can be summarized by distinguishing three different periods that correspond to different models of innovation (Joly 2006; Meynard et al. 2012): a linear relationship during the productivist period; an interactional relationship during the period when the productivist model was being questioned; and the search for alternatives, more and more reflective and multi-actor based since that sustainable development has become a founding principle of public policy.

8.2.1.1 The Productivist Model and Linear Innovation

Constructed in the context of the post-war period to achieve food self-sufficiency in France (reached in 1959) and Europe (achieved in 1980), this model achieved its full development during the "Thirty Glorious Years" from 1945 to 1975. It benefitted from the support of the European Common Agricultural Policy, and a strong commitment both from the farming community and the French State. This alliance gave rise to a pyramidal form of development intended to develop technical and regulatory innovations to increase the volume of production per hectare, to restructure farms and to promote regional specialization in relation to different production sectors. At the top of this pyramid, agronomic research was completely dedicated to the generation of knowledge for genetic improvement, increased agronomic performance and to the rural economy. The link between research and development followed a linear pattern and was top-down in relation to technical innovation resulting from research; it was supported by professional organizations and private companies, while the farmer was just the final destination. The great success of this model in France was based on the technical progress made by farmers, but also to the national, professional, scientific and political consensus which built and supported this model (Gervais et al. 1976). The current French agricultural landscape – family agriculture, productive specializations of agricultural regions, the economic logic and organizations of actors – is still largely structured by this model of development.

8.2.1.2 Alternative Models and Agricultural Interactive Innovation

The productivist model went into crisis in the 1970s and 1980s. The oil crisis led to an increase in the price of inputs. Agricultural overproduction led to reform of the

European Common Agricultural Policy (CAP) from the 1980s. Finally, environmental criticism began to emerge, in particular concerning water pollution by nitrate. Gradually, criticism began to challenge the dominant model. It is in this context that the INRA SAD division was created. The goal of the researchers that this new department was based on is to develop a new orientation of research. This orientation starts from an understanding of the practices and decisions of farmers (Sebillotte 1974), promotes a systemic approach at the farm scale (Osty 1978), broadens agricultural issues to local and landscape dynamics (INRA-ENSSAA 1977), and in so doing, leads to the rethinking of agricultural innovation. The search for alternatives is in vogue because this is the period in which local development promotes the diversification of agricultural development models (Jolivet 1988) as well as the recognition of the multifunctionality of agriculture and rural areas (Hervieu 2002). The research and development unit testing new innovations in agricultural systems takes into account the environment and adding value to the land in marginalized rural areas (Brossier et al. 1993). Agronomic research is also involved in research programs on organic farming. This diversification of models is associated with the interactionist approach to innovation, especially as advocated by the SAD Department, which is experimenting with action research approaches involving farmers and researchers working together to explore innovative solutions (Albaladejo and Casabianca 1997).

8.2.1.3 Sustainable Development, Agro-ecology and Open Innovation

The most recent period has been marked by French and European public policies that make innovation the major lever of “smart” development. This phenomenon affects all public policy sectors, including agriculture. In the background of this new approach to innovation, we find a de-structuring of past development models, and the search for the development of local specificities in the context of globalization. Agricultural innovation is now seen in the context of systems and networks of actors that cooperate at multiple scales, from local to global. Innovation has become like a whirlwind, that is to say, contingent (Gaglio 2011), in the context of an open design (Le Masson et al. 2006). Anyone can be an actor: it is the ordinary innovation, by use, by place, which is then implemented (Alter 2000). In this open environment, which is uncertain and fuzzy, agronomic research adapts by rethinking its paradigms, positions and methods. It must be able to offer solutions for sustainable agriculture in a context dominated by the productivist model that seeks to renew the green-economy or bio-economy. This is a context that also opens opportunities for innovation by reintegrating the plurality of alternative solutions by encompassing new paradigms such as agroecology (Wezel et al. 2009) that provides an interdisciplinary framework to develop sustainable food systems (Esnouf et al. 2013).

In summary, the relationship between innovation and development has changed profoundly. On the one hand, the objects and actors of agricultural innovation have expanded and diversified, breaking down sectoral and institutional boundaries. On the other hand, the dominant mecanisms coming from the productivist period still persist and prevents alternative innovations from taking over. To better understand this contradictory situation, we now consider the example of a particular French region: the Seine Basin near Paris.

8.2.2 Example of a French Region of Arable Farming

8.2.2.1 The Seine Basin in France

Since the beginning of the productivist period, the current landscapes of the North of France have been configured by a territorial specialization and production systems. The West (Brittany, in particular) for example, became an area dedicated to intensive farming, while the Paris Basin became dedicated to field crops, with very little animal husbandry. Mixed farming systems, once strongly represented in most regions, have become fewer and fewer. Figure 8.1 (taken from Schott et al. 2010) illustrates the consequences of this evolution in terms of land use.

These maps represent the watershed of the Seine (to the North West, the Normandy coast, and to the South East, Morvan), or about 100,000 km^2. The decline in ruminant livestock in the centre of the watershed basin is reflected on the map by the sharp decline in the area of natural meadows and through increased crop areas, the first of which, wheat, now occupies more than 50 % of the agricultural area. Livestock remains only in the peripheral areas of the basin, where forage corn is grown. This specialization poses environmental problems: biodiversity loss linked to the replacement of grasslands by annual crops, but also to the homogenization of the mosaic of habitats, the reduction of wetland areas related to drainage associated with the cultivation of grasslands, the lack of recycling of mineral elements (N, P, K ...) in the farms and the waste of non-renewable resources.

This territorial specialization is driven by the agro-industrial companies which provide the outlets for these products. In a context of increased technicality of the various stages of production, farmers, like their advisers, update their skills just in their areas of specialization. Diversifying becomes more difficult for a farmer given that he or she must not only find opportunities that no longer exist locally, but also must acquire without local support the knowledge and technical information concerning new products.

8.2.2.2 The Key Role of Pesticides

This regional specialization would not be possible without pesticides: shorter crop rotations increase soil parasites and weed populations, while the homogenization of crop mosaics increases the risk of outbreaks of airborne parasites. Pesticides have become the cornerstone of current intensive cropping systems, and configure not only the rotations, but also the crop management. Thus, to maximize wheat yields,

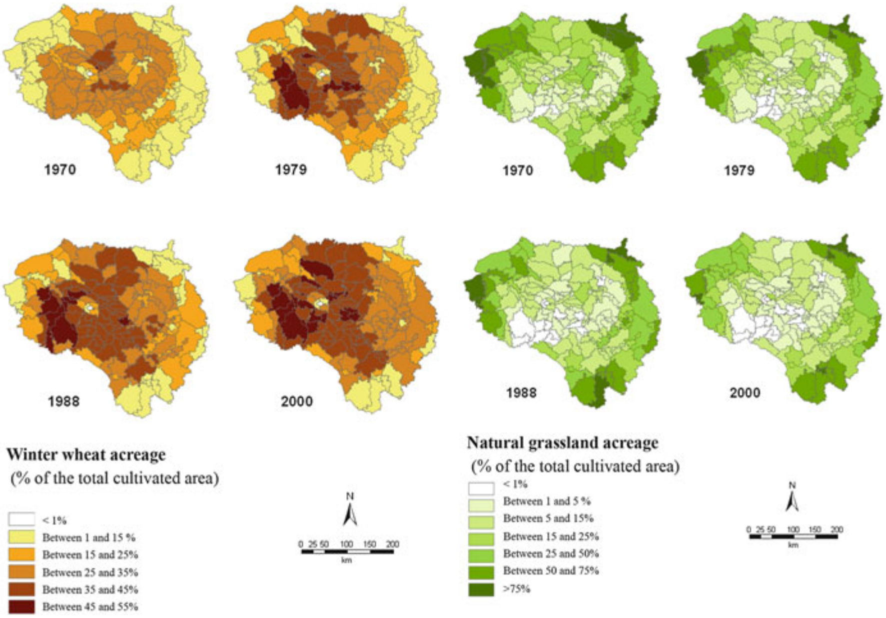


Fig. 8.1 Evolution of land use in the Seine Basin, between 1970 and 2000: winter wheat and natural grassland acreages

the crop is sown early and densely, high levels of nitrogen fertilizer are applied, and the most productive varieties are chosen (which are usually not the most disease resistant). All these choices are favorable to productivity but also to insect parasites, fungal diseases and weeds . . . and to the use of pesticides!

Companies that market pesticides have become major players in providing technical advice. This favors simple solutions (one issue, one input) rather than preventive agronomic practices that are more complex to implement and less effective immediately. Varietal resistance is often seen as being complementary to pesticides, and not as privileged means of control. So, the market for multi-resistant varieties is limited, which does not encourage seed companies to focus on this market niche. Given this secondary role of varietal resistance, there is no coordination of varietal choices to improve resistance management, and the common bypass of varietal resistance tends to discredit this alternative solution (Meynard 2013).

8.2.2.3 Locked-in Farming Systems

Agricultural production systems thus appear as fully consistent with the organization of upstream and downstream sectors, as well as with information dissemination systems. The strategy of each player reinforces the strategy of others. No one really has any interest in changing their strategy, as long as the others do not change. We are thus in a typical case of what researchers in sociology and the economics of innovation have called "technological lock-in". The role of pesticides in agricultural lock-in has been described in the USA by Cowan and Gunby (1996) and in Belgium by Vanloqueren and Baret (2008). This very coherent socio-technical system is the result of the remarkable response from the agricultural sector to public policies oriented towards increasing grain production and labor productivity. This consistency clearly clashes with any new orientation that environmental consideration suggests, but it will not be possible to change the modes of production by a simple effort of encouraging innovation in alternative strategies and providing information for farmers on these innovations: the fundamental answer must simultaneously involve mobilizing all stakeholders to "unlock" the system.

Finally, faced with such locked-in situations, which are relatively common in intensive agriculture, it is necessary to think of innovation by working on the relationships between different development models. Multi-level analyses emanating from the transition theory (Geels 2002) open new ways to think about the contribution of agronomic research to innovation, taking into account the general trends of the dominant regime as representing weak signals revealed by the innovation niches.

8.3 Rethinking the Contribution of Research to Innovation in Agriculture: Tips

Long-term developments have identified the brakes and levers that must be considered to drive innovation in the current context. Agroecology is one of the first possible ways that opens up new perspectives on the postures, methods and practices of agronomy. The re-territorialisation of agriculture is a second way to think of the forms of agricultural development that rely more on local resources and social ties.

8.3.1 The Path of Agroecology: Designing Sustainable Agricultural Systems in Other Ways

The strong coherence which governs technical choices, as much as the complexities of agro-ecosystem regulations invite researchers to think in a systemic way: to take into account the unintentional effects of technical choices, to consider the interactions between techniques and to integrate several scales and temporal time lines.

Agroecology, defined as the ecology of food systems (Francis et al. 2003), constitutes a response to this need for a systemic approach. For example, it involves controlling pests by promoting their predators and crop resistance, using the diversity of landscape mosaics as a source of resilience for the agro-ecosystem and using legume crops to supply nitrogen to the other plants. The global vision of the production–consumption relationship encourages the exploration of agro-food systems by associating local produce consumption, development of short distribution chains and diversification of production systems and landscape mosaics, as opposed to the dominant system, which links together long distribution chains, specialization and the uniformity of landscapes (Lamine et al. 2012). There is a pressing need to re-design cropping and farming systems!

A review of the scientific literature about design of cropping and farming systems (Meynard et al. 2012) reveals the existence of two major sets of approaches: "*de novo* design", and "step by step design".

De novo design aims to determine innovative systems without worrying, at least initially, about transition or about how to go from the current system to the new one. What is essential is to invent something that marks a break. Collective design workshops offer very favourable conditions to *de novo* design, but the composition of the group and the management of the workshop appear to be essential. The use of agronomic models is also a very effective way for *de novo* design: combinations of techniques can be very extensively explored, well beyond what the best experts know, and inform the designers about the long-term behaviour of the systems they invent, as well as on the probable effects of climate change. From a large number of possibilities, the models make it possible to identify combinations of technical choices which satisfy a set of specifications, in terms of production, income, work or environmental impacts. Many research teams, in different countries, use crop models or cropping system models to design innovative cropping systems. Work currently in progress is concentrating on how to mobilise non-scientific knowledge in a model-based design.

In step-by-step design, the focus is not on the future system, but on the management of change. An existing system is used as the starting point; it is gradually modified to arrive at an innovative system which was not precisely known in advance. The design work begins with a diagnosis. The diagnosis identifies the key points of the farming system to be improved, and makes it possible to imagine modifications to practices or organization that are likely to improve the situation. After implementation of these changes, a new diagnosis is carried out, which verifies whether the situation has been improved, and determines new priorities for change. It represents a real loop of continuous improvement that is getting under way. Compared with *de novo* design, this exploration is more careful, but the result may be just as innovative. Step by step design has the advantage of adapting easily to the specific constraints of each farming situation. It lends itself well to a progressive mobilization of farmers, in a development approach. The farmer, often supported by an advisor or a collective of his or her peers, perfects his or her new system year by year, and at the same time learns how to control it. He or she convinces him or herself of its performance, and gradually reorganizes the work and means of production. Lamine et al. (2011) showed the importance of farmers' discussion groups in such learning approaches to innovative systems; they serve as a source of ideas and contribute to sharing experience and providing moral support in the face of risk-taking.

8.3.2 The Territorial Pathway: Supporting Actors Relocalise Agricultural Systems

In France, the regionalization of agriculture has taken a new turn since the recent orientations laws have appropriated the multi-functionality of agriculture. This has led to the recognition that relationships between farmers and territories are not based only on the production of food products, but also taking into account the environment and the provision of agricultural services and many other functions. Meanwhile, continuing decentralization has created laws that have reformed territorial administration and development by promoting regional development across regions and inter-municipal structures. Agriculture then found itself included in local rural, urban, environmental, energy and employment policies, among others. The third concomitant process was the application of sustainable development principles into policies and initiatives that promote citizen participation: public inquiries, discussion forums, neighborhood committees, and others are all discussion arenas to which agriculture can find itself convened. Agronomic research cannot ignore these developments which farmers are facing. Collaboration between agronomic and social science researchers is needed to contribute to territorial innovations. Our work has led us to distinguish three levels of relationship between agriculture and territory: the farm, the territory of local collective action, and areas for the application of local public policy.

8.3.2.1 Farmers Innovate on Their Territory

At the scale of the farm, our interviews involving farmers in several small French regions located in wetland areas, show contrasting relationships with the multi-functionality of different territories (Soulard 2005a). The implementation of multi-functional practices involves a number of territorial and land requirements that are very different from one farm to another and even from one place to another of the same farm. Farmers must then conceive of case by case combinations of the most appropriate practices. To achieve this, they have to call upon and combine a wide range of practical innovations in (i) production techniques, (ii) the land use management practices of the area, particularly including the connections between agricultural land and natural areas, (iii) the ecological monitoring of the effects of practices on the natural environment and (iv) social practices, in order to create alliances between local actors or to prevent or regulate conflicts of use. At this scale, the geography of practices on the farmer's workspace allows the identification of innovative practices that find coherence between agricultural logic of the farm and territorial challenges (Soulard 2005b). However, these relationships are not always and everywhere possible, and almost always they will complicate the farm's technical system. The prevailing agricultural practices then remain predominantly sectoral.

8.3.2.2 Researchers and Actors Cooperate to Innovate

In a territory-wide action, the multi-functionality of agriculture involves negotiation of trade-off between actors with sometimes conflicting interests. The management of sensitive natural areas illustrates this problem. In this context of territorial development, researchers operate differently. Their role is not only to observe but also to support the consultation process. Continuing with the example of wetlands, our involvement led to the construction of learning infrastructures, i.e. organizations that can enable diverse actors develop compromises for sustainable land management. The multi-actors approach is of great help in conducting such steps that must mobilize actors by taking into account their different logics of action. This involves the researcher constructing intermediary tools (Trompette and Vincq 2009) that will help the dialogue. For example, we developed a tool to help identify management practices in a flood zone. Figure 8.2 is designed to engage three actors: farmers who produce fodder in flood zones, managers of wildlife, flora and water resources, and the municipality and the land owners who manage the flood plain and its facilities. In this case, the multi-level agroecological systems approach led to the development of a concerted regional action plan (Soulard and Kockmann 2012). Here the contribution to innovation depends upon social experimentation: a real development situation that involves researcher combining observation, expertise and support for dialogue.

8.3.2.3 Agricultural Research Expected in Relation to Public Policy

Finally, these initiatives in the territorial development domain are linked to broader scales: policy makers, whether national, regional or local. The work at these scales is more recent for agronomic research, which has been traditionally linked to the professional communities of agriculture. However, there is an increase in the strength of actors who develop agricultural policies at sub-national levels, with expectations closer to those of citizens who often desire agricultural innovations for local agricultural systems, organic farming, short food chains, and actions oriented to employment or social inclusion. The most obvious phenomenon is the entrance of cities in relation to the implementation of regional policies, including agriculture and food. The phenomenon is global but dispersed (Viljoen and Wiskerke 2012). Agronomic research must move its field of investigation, because it is in the heart of the cities and their peripheries where new agricultural systems are evolving and being experimented with. The contribution to innovation is being handled by actors often removed from the agricultural sphere, and agronomic research is expected to provide a bridge between urban and agricultural worlds (Soulard and Aubry 2011). The contribution to innovation involves new research dimensions, such as constructing regional futures to simulate scenarios for agricultural development, or the development of agricultural databases integrated into territorial observatories.

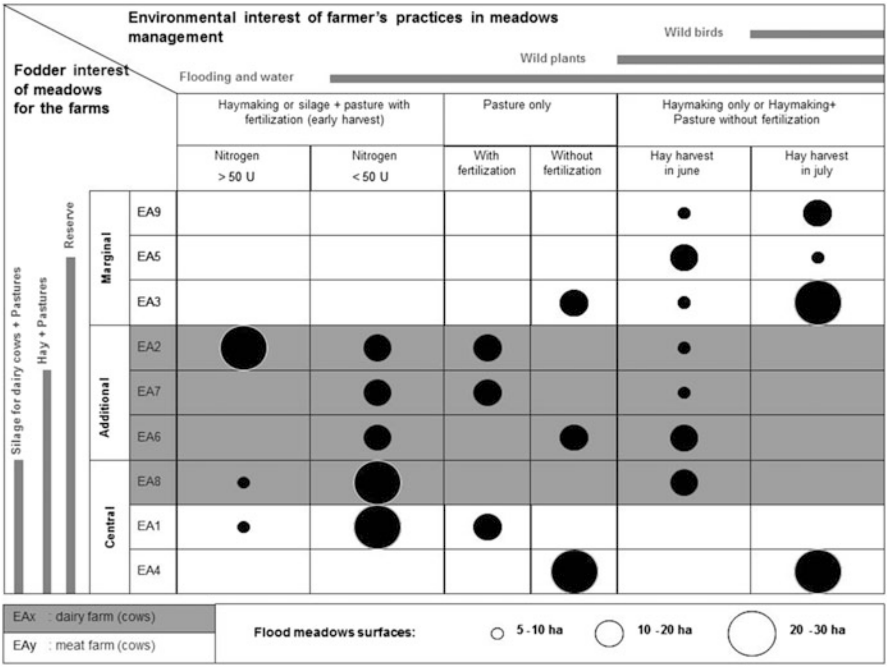


Fig. 8.2 Classification of flood-prone meadows according to their interest for fodder production and environmental interest

In conclusion, through territorial intervention agronomic research is experiencing a renewal in relation to the objects of research it must now deal with, but also in relation to the methods that are being used in this research.

8.4 Conclusion: Climate Change: A New Deal for Innovation?

The consideration of climate change leads to considering the innovation pathways that can help to reduce the impacts or to anticipate the necessary adaptation strategies. This forward-looking approach to innovation needs to act simultaneously and in a coordinated manner on different levers, with different actors and at different scales to overcome the "locks" and activate the relevant innovations. It is important to think globally about agroecological transitions of agricultural systems, by dealing both with information about the past and the future. Researchers must therefore be involved in the local co-design of innovative agricultural systems, combining the scientific knowledge of researchers, the practical knowledge of farmers and the political projects for territories. They must engage therefore in social experiments and action research.

However, designing innovations taking into account climate change calls into question the knowledge base of farmers and advisors, and particularly the relevance of the know-how they acquired in the past. To rebuild their capacity to project themselves into the future, farmers and advisors must necessarily combine their empirical local knowledge with knowledge derived from climate and agro-ecological models. It is evident that the design process must mobilize a collective and shared intelligence, more efficient, faster and less dangerous than individual approaches, that are dependent on dominant disciplines or local representations (Lançon et al. 2008). This supposes the organization of complementarities and an increase in communication between the various actors in the innovation: researchers, R&D engineers, farmers, breeders, the authorities. . ... The impact of innovations should be assessed ex ante and ex post, at different scales, in order to provide learning at different levels: farm and territories exposed to climate change, and up to public policy.

In conclusion, this reflection on new approaches to agricultural innovation raises questions about strengthening research systems that contribute to innovation, from the design of new ideas within the "outdoor laboratory" where researchers and actors co-build solutions within "communities of practices" to their appropriation by institutional actors who influence the choices of public and private decision makers.

References

Albaladejo, C., & Casabianca, F. (1997). *La recherche-action. Ambitions, pratiques, projets.* Études et recherche sur les systèmes agraires et le développement, INRA-SAD, n°30.

Alter, N. (2000). *L'innovation ordinaire*. Paris: PUF (Sociologies).

Brossier, J., de Bonneval, L., & Landais, E. (1993). *System studies in agriculture and rural development*. Paris: INRA Editions.

Coudel, E., Devautour, H., Soulard, C. T., Faure, G., & Hubert, B. (2013). *Renewing innovation systems in agriculture and food: How to go towards more sustainability?* Wageningen: Wageningen Academic Publishers.

Cowan, R., & Gunby, P. (1996). Sprayed to death: Path dependence, lock-in and pest control. *Economic Journal, 106*(436), 521–543.

Darnhofer, I., Gibbon, D., & Dedieu, B. (Eds.). (2012). *Farming systems research into the 21st century: The new dynamic*. Dordrecht: Springer.

Esnouf, C., Russel, M., & Bricas, N. (Eds.). (2013). *Food system sustainability: Insights from DuALIne*. Cambridge: Cambridge University Press.

Francis, C., Lieblein, G., Gliessman, S., Breland, T. A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C., & Poincelot, R. (2003). Agroecology: The ecology of food systems. *Journal of Sustainable Agriculture, 22*, 99–118.

Gaglio, G. (2011). *Sociologie de l'innovation*. Paris: PUF.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy, 31*(8–9), 1257–1274.

Gervais, M., Jollivet, M., & Tavernier, Y. (1976). La fin de la France paysanne de 1914 à nos jours. In G. Duby & A. Wallon (Eds.), *Histoire de la France rurale*. Paris: Ed Seuil, Tome 4.

Grafagri, (2011). *Rèsultats èconomiques de l'agriculture*. Paris: Ministère de l'agriculture. http://agreste.agriculture.gouv.fr/IMG/pdf_Gaf11p046.pdf.

Hervieu, B. (2002). La multifonctionnalité de l'agriculture: genèse et fondement d'une nouvelle approche conceptuelle de l'activité agricole. *Cahiers d'études et de recherche francophone/ Agriculture, 6*, 415–419.

INRA-ENSSAA. (1977). *Pays, paysans, paysages dans les Vosges du sud*. Paris: INRA.

Jollivet, M. (Ed.). (1988). *Pour une agriculture diversifiée*. Paris: L'Harmattan.

Joly, P. B. (2006). Transformations de l'innovation en agriculture. Une analyse par les sciences sociales. In J. Caneill (Ed.), *Agronomes et innovations* (pp. 3–29). Paris: L'Harmattan.

Lamine, C., Messéan, A., Paratte, R., Hochereau, F., Meynard, J. M., & Ricci, P. (2011). La lutte chimique au cœur de la construction du système agri-alimentaire [Chemical applications as the heart of agro-food system building]. In Ricci, Bui, & Lamine (Eds.), *Repenser la protection des cultures; innovations et transitions* (pp. 30–58). Versailles: Quae-Educagri.

Lamine, C., Renting, H., Rossi, A., Wiskerke, H., & Brunori, G. (2012). Agri-food system and territorial development: Innovations, new dynamics and changing governance systems. In Darnhofer, Gibbon, & Dedieu (Eds.), *Farming systems research into the 21st century: The new dynamic*. Dordrecht: Springer.

Lançon, J., Reau, R., Cariolle, M., Munier-Jolain, N., Omont, B., Petit, M.-S., Viaux, P., & Wery, J. (2008). Elaboration à dire d'experts de systèmes de culture innovants [Innovative cropping systems design by experts]. In R. Reau & T. Doré (Eds.), *Systèmes de culture innovants et durables* (pp. 91–108). Dijon: Educagri.

Le Masson, P., Weil, B., & Hatchuel, A. (2006). *Les processus d'innovation: Conception innovante et croissance des entreprises* [Innovation processes: innovative design and entreprises growth]. Paris: Hermes Lavoisier.

Meynard, J. M. (2013). Innovating in cropping and farming systems. In E. Coudel et al. (Eds.), *Renewing innovation systems in agriculture and food: How to go towards more sustainability?* (pp. 77–86). Wageningen: Wageningen Academic Publishers.

Meynard, J. M., Dedieu, B., & Bos, A. P. (2012). Re-design and co-design of farming systems. An overview of methods and practices. In I. Darnhofer, D. Gibon, & B. Dedieu (Eds.), *Farming systems research into the 21st century: The new dynamic*. Dordrecht: Springer.

Osty, P. L. (1978). L'exploitation agricole vue comme un système. Diffusion de l'innovation et contribution au développement. *Bulletin Technique d'Information, 326*, 43–49.

Schott, C., Mignolet, C., & Meynard, J. M. (2010). Les oléoprotéagineux dans les systèmes de culture: évolution des assolements et des successions culturales depuis les années 1970 dans le bassin de la Seine [Oilseeds in cropping systems: Changes in rotations since 1970 in the Seine water basin]. *Oleagineux, Corps Gras, Lipides, 17*, 276–291.

Sebillotte, M. (1974). Agronomie et Agriculture. Essai d'analyse des tâches de l'agronome. *Cahiers ORSTOM, 24*, 3–25.

Soulard C. T. (2005a). La multifonctionnalité de l'agriculture en pratique : étude des relations entre exploitations agricoles et étangs de la Dombes. *Cybergeo, European Journal of Geography, 319*, 12 p. On line: http://cybergeo.revues.org/6610

Soulard, C. T. (2005b). Les agriculteurs et la pollution des eaux. Proposition d'une géographie des pratiques. *Natures Sciences Sociétés, 13*(2), 154–164.

Soulard, C. T., & Aubry C. (2011). Cultiver les milieux habités. Quelle agronomie en zone urbaine ? *Revue Agronomie Environnement & Sociétés*, *2*(8), 89–101. On line : http://www.agronomie.asso.fr/carrefour-inter-professionnel/evenements-de-lafa/revue-en-ligne/revue-aes-vol1-n2-decembre-2011/revue-aes-vol1-n2-8/

Soulard, C. T., & Kockmann, F. (2012). Concevoir un projet territorial agroenvironnemental. Le concept de système agraire revisité. In S. Lardon (Ed.), *Géoagronomie, paysage et projets de territoire. Sur les traces de Jean-Pierre Deffontaines* (pp. 271–287). Paris: QUAE Editions – NSS Dialogues.

Trompette, P., & Vinck, D. (2009). Revisiting the notion of boundary object. *Revue d'anthropologie des connaissances, 3*(1), 3–25.

Vanloqueren, G., & Baret, P. (2008). Why are ecological, low-input, multi-resistant wheat cultivars slow to develop commercially? A Belgian agricultural 'lock-in' case study. *Ecological Economics, 66*, 436–446.

Viljoen, A., & Wiskerke, J. S. (Eds.). (2012). *Sustainable food planning: Evolving theory and practice*. Wageningen: Wageningen Academic Publishers.

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., & David, C. (2009). Agroecology as a science, a movement and a practice. A review. *Agronomy for Sustainable Development, 29*(4), 503–515.

Christophe-Toussaint Soulard is a researcher at the French Institute for Agricultural Research, based in Montpellier, France. With a PhD geography in 1999, his PhD work focused on the relations between the geography of farmer's practices and water pollution management in France. From 2010 to 2014, he was director of the joint research unit "UMR Innovation" which studies the innovation and development processes in Agriculture and Food. For the last 10 years, he has been head of a multidiscplinary research group which analyses the the innovations connecting agriculture, food and the cities. He managed the international DAUME project focusing on the sustainability of urban agriculture in the Mediterranean. He is also recognized for his work involving action research. In 2015, his team supported the metropolitan council of the City of Montpellier (a population of 450,000) to develop an agricultural and food policy.

Jean-Marc Meynard is a senior researcher at the French Institute for Agricultural Research (INRA), based in Grignon (near Paris). He is a cropping system agronomist, and obtained his PhD in 1985, entitled "Design of crop management systems for winter wheat". His research is mainly focused on the design of low input cropping systems and integrated pest management, and with the collaboration of social scientists on socio-technical lock-in that hampers pesticide reduction and crop diversification. From 2003 to 2012, he was head of one of the 13 scientific divisions of INRA, the "Sciences for Action and Development" division, which carries out multidisciplinary and participatory research programs on collective action, innovation processes, socio-technical systems and territorial development, related to agriculture and food. He is now President of the French Scientific Council for Organic Farming, and of the Scientific Council of the Chambers of Agriculture.

Part II
Africa

Chapter 9
Low Frequency Winter Rainfall Variability in the North West of Morocco

Ali Bellichi

Abstract The main characteristic of the rainfall climate in the North West of Morocco is its strong interannual variability which is due to its eccentric latitudinal position on the fringe of the North Atlantic mid-latitude baroclinic region. Linked to the North Atlantic large scale circulation variation and winter extra-tropical disturbance, the rainfall events in our region are closely connected to the NAO regime as the dominant winter mode of low-frequency variability over the North Atlantic sector. The swings between one phase to another of this regime produce large changes in storminess and precipitation over our region. The temporal rainfall evolution over the last 60 years shows two characteristic sub–periods: the first one is dominated by more rainy winters from 1950–1951 to 1978–1979, and the second one has frequently experienced more dry winters, particularly between 1979–19 80 and 2008–2009 usually with many persistent and severe long drought episodes. Both sub–periods exist in a causal relationship with one of the two phases of the NAO. In the first sub-period, under the effect of a negative phase of this pattern, a southward shift in the storm–track is produced, which can easily reach our latitude and give rise to rainier winters. The second sub–period is subject to an increase in frequent persistent and intensive positive phase events, which generate enhance a northward shift of the mid-latitude storm–track and deficiency conditions, and which can affect our region substantially.

Keywords North West Morocco • Winter rainfall variability • North Atlantic Oscillation • Intense irregularity

9.1 Introduction

The Moroccan rainfall climate is characterized by a rather erratic intra and inter-annual variation that is quite evident; this refers to the overall variability of rainfall events whose frequency and intensity are very much dependent on the state of the general circulation and its changes in our latitudes. The general trend which has

A. Bellichi (✉)
University of Mohamed V, Rabat, Morocco
e-mail: a.bellichi@flsh.um5a.ac.ma

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_9

been present over the last six decades reflects a net decrease in annual rainfall quantities with a rather mixed seasonal distribution. The analysis of the overall variability of rainfall and its intra – annual irregularity in the literature uses various methods while overall giving a prominent place to the relations with some major modes of atmospheric circulation (Hurrell 1995).

Many studies have already shown the more or less marked influence of the evolution of atmospheric conditions on the overall variability of climate elements (Goodess and Jones 2002; Herrera et al. 2003; Kucharski and Molteri 2003; Trigo et al. 2002; Quadrelli et al. 2001; Martin-Vide and Lopez-Bustins 2006; Haylock and Goodess 2004; Lorenzo et al. 2008; Ortizbevia et al. 2011; Knippertz 2004; Hurrell and Deser 2009). Thus, taking account of a more structured approach, a certain number of major circulation patterns with repeated occurrence contributes to a better understanding of the evolution of the average isobaric situation patterns which as a consequence shapes the basic features of the climate and its character.

The notion of weather regime (*weather régime*) seems to sum up perfectly the evolution of general circulation in the North Atlantic and Western Mediterranean. The concept itself as it is introduced in the specialized literature by synopticians since the early 1950s, is based on the idea of atmospheric circulation evolving between a limited number of atmospheric states (Plaut and Simonnet 2001; Michelangeli et al. 1995).

These weather patterns and their temporal succession are now regarded as the main factors underlying much of the variability of weather and climate in their area of influence (Hurrell and Deser 2009). The geographical position of Morocco in the area of influence of the Azores anticyclone, one of the main structural poles of these major patterns of movement, place it in the context of the atmospheric dynamic that is strongly marked by fluctuations in space and in time, the famous "depression or storm track". This governs most of the rainfall conditions of the middle and subtropical latitudes (Kvamto et al. 2008).

Four weather regimes define the main configurations of the general circulation of the North Atlantic, as identified by Vautard (1990), Michelangeli et al. (1995), Cassou et al. (2004), and Cassou (2008): The Blocking regime, the Atlantic Ridge, and both the positive and negative phases of the North Atlantic Oscillation (NAO).

Of these four régimes, only the latter two are considered to be those that mark the most deeply in terms of intensity and orientation the disturbed mid-latitude flows and therefore the overall variability of precipitation in this area of the North Atlantic (Barnston and Livezey 1987; Hurrell and Deser 2009; Shabbar et al. 2001; Trigo et al. 2002; Rodriguez Fonseca et al. 2006). In other words, it is the alternating passage from one situation to another including intermediate or transitional situations, which determine most of the general variation in rainfall climate of our region. The relatively eccentric position of our latitudes in particular, and of the Mediterranean in general, that influences our weather regime possesses a special character to the extent that the alternation of two phases of the NAO undeniably brand and roughly determines the length of the rainy season in the winter months. The highly variable trajectories of depressions here more than anywhere else, give the rainfall in our region its character at times random and certainly very irregular.

9.2 The Data

The data used for this study are first monthly precipitation amounts from the Global Precipitation Climatology Centre (GPCC) (GPCC Full Data Reanalysis Version 5) and spatilized by grid points, covering the north western area of Morocco. We selected seven grid points with a resolution of 2.5° × 2.5 ° (P1: 35°N 7.5°W; P2: 35°N 5°W; P3: 32.5°N 10°W; P4: 32.5°N 7.5°W; P5: 32.5°N 5°W; P6: 30° N 7.5°W; P7: 30°N 5°W) (Fig. 9.1). Data were used with a geopotential of 500 hPa from NCEP/NCAR, of 5° × 5° extending from latitude 25 to 60° North and 60°W to 40°East, or about 168 grid points. The values of the NAO index are based on the pressure difference between the ground stations of Gibraltar and Akureyri (Iceland). All these data were recalculated to transform them into a seasonal winter series (December, January, February) over the period 1950–51 to 2008–09.

9.3 An Intensely Variable and Very Erratic Rainfall

Winter precipitation averaged about 40–45 % of annual totals recorded in our region, which gives them a dominant role as the main component of rainfall. The contribution of these winter rains is essential in defining and determining the

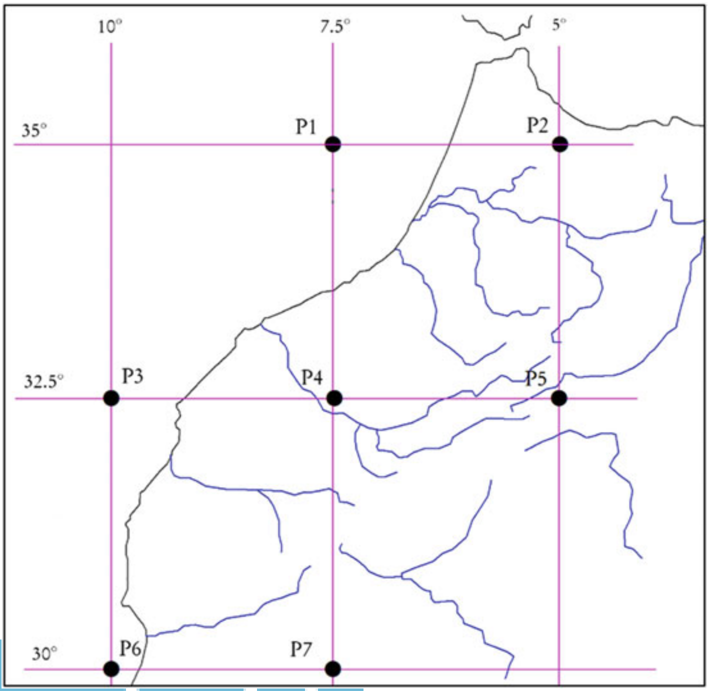


Fig. 9.1 Sketch of the locations of the grid points used

average rainfall profile, and their fluctuations directly affect the agricultural and water potential of the wettest part of the country.

The rainfall during this season generally follows two gradients more or less characteristic, first and most importantly from north to south and secondly, of lesser importance, from west to east. If the northern part of the country is favoured mainly because of its latitudinal position that makes it more subject to the different trajectories of perturbations and therefore is thus the wettest, the southern part is less so, due to the low frequency on average of disturbances. On average (normal for winter 1960–1961/1989–1990): 229.27 mm (35°N 7.5°W), 152.34 mm (35°N 5°W), while further south these averages remain below 41.68 mm and 25.90 mm respectively for the grid points (30°N 10°W and 30°N 7.5°W).

The rains of this season increase steadily towards the interior under the effect of the altitude on the western slopes of the Rif mountains in the north and of the Middle Atlas in the centre, before declining significantly further east on the eastern slopes of these mountains. This is even more evident in the central part of our region, the winter normal of which is just slightly over 100 mm: 118.52 mm and 110.71 mm respectively for the grid points 32.5° 10°W and 32.5°N 7.5°W. On the same latitude but located much further to the east, the grid point 32.5°N 5°W only receives on average 26.30 mm.

9.3.1 Temporal Evolution of Two Contrasting Sub-Periods

Changes in seasonal winter heights over the last 60 years from 1950–1951 to 2008–2009 show a distribution dominated by a relatively high variability which is essentially characterized by being relatively higher in the wetter north with more rainfall than the southern sector, and in coastal areas more than in the interior (Fig. 9.2). One observes as well an irregularity that is much stronger in the north than in the south.

The temporal distribution of the heights of winter precipitation during the study period generally shows a succession of quite variable and contrasted periods of rainfall that denotes generally a highly volatile and highly irregular character.

A sensitive wetness characterizes the winters of the 1950s, 1960s and 1970s, which stand out in terms of the volume of rainfall that generally exceeds the seasonal norm, sometimes with maximum concentrations as was the case in 1955–1956 which sometimes had a cumulative total of $+3\ \sigma$ $+5\ \sigma$ in the center and south of the region. In contrast, the winter of 1958–1959 experienced a significant deficit for the country as a whole with volumes that occurred below -1σ and -1.7σ in the north and centre. During the 1960s, the winters of 1962–1963, 1963–1964 and also that of 1964–1965 which posted the second largest volumes of rainfall exceeding $+1\ \sigma$ $+2\sigma$ everywhere. The two successive winters of 1965–1966 and 1966–1967 showed on the other hand very low rainfall amounts of about $-0.6\ \sigma$ and -1.5σ.

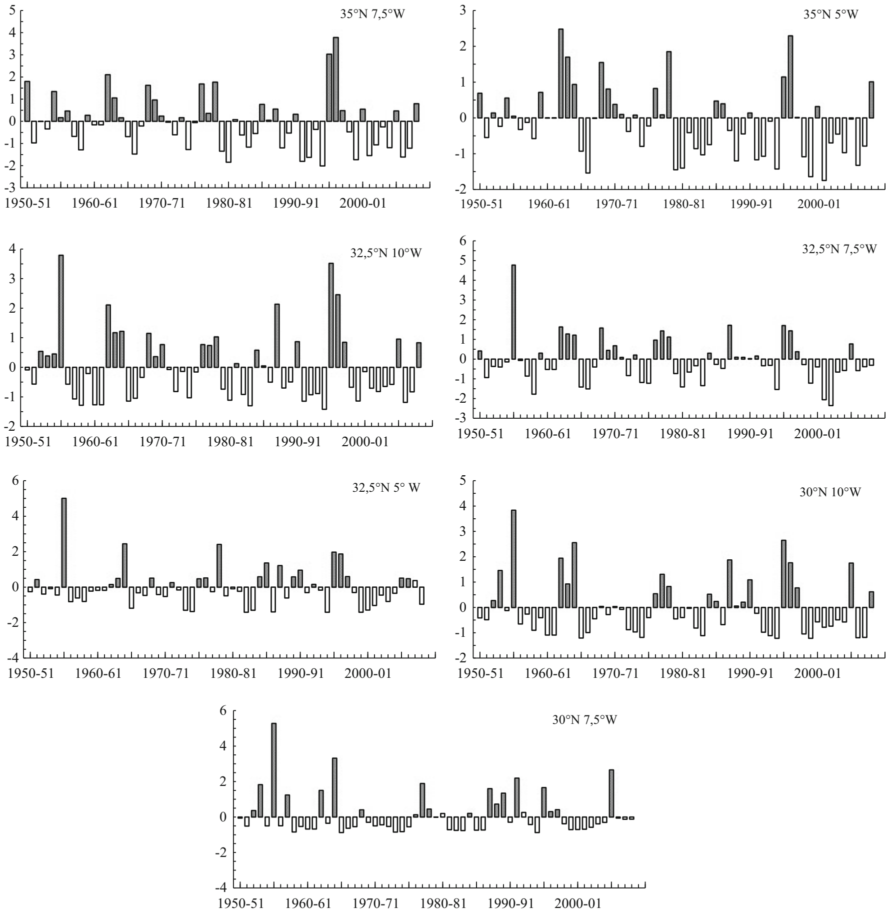


Fig. 9.2 Temporal evolution of deviations from the normal (1961–1962 to 1990–1991) of the winter totals from 1950 to 1951/2008 to 2009 of the different grid points selected

The 1970s saw overall a very average rainfall with volumes around $\pm$ 1σ, but with a significant winter 1974–1975 deficit everywhere, with quite low volumes showing differences in the order of -0.7 σ to -1σ. The winters of 1977–1978 and 1978–1979 marked a short period of significantly high rainfall where almost everywhere one notes excess values and relative concentration of rainfall around +1σ to 1.5σ in the north and centre, particularly during the 1978–1979 season.

The year 1979–1980 marks the beginning of a period of recurrent rainfall deficit especially in the winter, which significantly differentiated it from the average rainfall profile over the previous three decades. General weakness and predominant rainfall of this period contrasted remarkably with the first period of the study which identified an increased frequency of years with very few rainy winters and with deviations from the normal dropping significantly each time below -1σ. This is thus a period that saw widespread and recurrent droughts, notably in1979–1980/ 1983–1984, 1991–1992/1994–1995, 1998–1999/1999–2000, 2001–2002/ 2002–2003 and 2006–2007/2007–2008. The generalized deficit which hit the country over the past three decades has been of an unparalleled intensity and persistence so far. Some years in this period were illustrated by the strong deficit of their winters such as those of 1979–1980 and 1980–1981 with some gaps that were around -2σ in the north and centre of the country. During the winter of 1983–1984, the winter drought extended throughout the country and the total rainfall remained well below -1σ. On the other hand, the 1987–1988 year was the only year when winter rains showed a surplus of about +1 to $+2\sigma$, mainly in the centre and south of the country.

The 1990s saw the phenomenon being further amplified and generalized, with the rainfall deficit affecting first the north of the country from 1991–1992 to 1992–1993 with anomalies of from -1σ to -1.6σ. The year 1994–1995 was one of the most severely dry years both in duration and scope, since it had not rained enough in any season and especially during the winter everywhere, and the rainfall deficit varied throughout the country from -0.87σ to -1.97σ. The next 2 years 1995–1996 and 1996–1997 experienced, however, extremely wet winters with high rainfall concentrations with volumes showing surpluses of $+1\sigma$ to $+3.5\sigma$ and $+1.4\sigma$ to $+3.7\sigma$ respectively. The very rapid pace of change reflects the highly irregular nature of the rainfall climate, and highlights the propensity to observe amplified interactions with extreme events. Two years later, the winter of 1999–2000 showed another negative anomaly of about -0.71σ to $-1.69\ \sigma$ across the country. The winters of 2000–2001 and 2001–2002 also show a generalized deficit of -0.42σ to $-.5\sigma$, but which reached almost -2σ in the centre.

Winter precipitation was fairly small during the period 2003–2004 to 2007–2008 with deviations from the normal generally around $-0.5\ \sigma$, with the exception of the winter of 2005–2006, which was relatively wet, especially in the south where it reached surplus of $+1.8\sigma$ to $+2.6\sigma$. The following years saw their winters accumulate very insufficient amounts of rainfall of the order of -0.5σ and -1.57σ, particularly in the north and south, while the winter of 2008–2009 was characterized by fairly average volumes especially in the north.

The comparison between the two sub-periods (Table 9.1) shows that the proportion of volumes larger than 1 standard deviation has a relatively higher frequency in the first compared to the second period. In contrast, the frequency of volumes less than 1 standard deviation is generally more important in the second period. In other words, it rained more heavily during the first period than in the second half which experienced more occurrences of average to modest cumulative averages, or even insignificant accumulations. The contrast between the two sub-periods is even more intense in the extreme north of the country which was significantly wetter. The incidence of low volumes shown here in the second sub-period increased by almost three to five times compared to the first sub-period, while relatively large quantities declined by two to three times during the second period.

Table 9.1 Percentage frequency of winter cumulative rainfall anomalies less or greater than one standard deviation for the two sub-periods (1950–1951/1978–1979) and (1979–1980/2008–2009)

	1950–1951/1979–1980		1980–1981/2008–2009	
	≥1σ (%)	≤1σ (%)	≥1σ (%)	≤1σ (%)
35°N 7.5°W	13.3	23.3	41.4	6.9
35° N 5° W	6.7	13.3	34.5	6.9
32.5° N 10° W	20	16.7	20.7	10.3
32.5° N 7.5° W	16.7	23.3	10.3	13.8
32.5°N 5° W	10	10	24.1	13.8
30°N 10° W	16.7	16.7	27.6	17.2
30° N 7.5° W	0	20	0	17.2

9.3.2 Increasingly Deficit Prone Winters in the North and Centre

Our latitudinal rainfall climate falls in the southern margin of the temperate and Mediterranean reference area accounts for its intensely variable and quite irregular climate conditions. The irregularity of the Mediterranean climate appears to be (according to Garcia-Barron et al. 2011) a key feature that emphasizes even more the reality of the non stationarity of the climate, specifically with regard to its latitudinal position.

The graphic display of Fig. 9.3 which shows the cumulative deviations from the average (normal) values reveals very clearly the dominant evolutionary trend on our rainfall data series. Thus, one can distinguish a first period characterized by the winters of 1950–1951 to 1978–1979 that is more or less humid, and whose rainfall levels often show deviations from the normal that overall are positive. The second period is characterized by a decreasing trend of the curve, which occurs in a two-time grouping first of the winters from 1979–1980 to 1994–1995, with a net decrease of rainfall during this season especially in the north (35°N). This decrease appears to be easing a bit in the centre of the country (32.5°N), and the intensity of this decrease is here more pronounced particularly along the coast. The advent of two exceptional years 1995–1996 and 1996–1997, and the maximum concentration of winter rainfall levels during these years have contributed significantly to cushion the sharp drop in levels after that date, while afterwards during the early 2000s there was a continuation of considerably greater negative deviations. However, the overall deficit that seems to characterize the latter period in the north and centre of the country appears to give rise to relatively differential intensities. In the north, this decrease appears to be common to both the coastal areas and inland initially and then becomes lower on the coast during the 2000s. In contrast, in the centre this general decrease in rainfall is more pronounced on the coast than in the interior although the differences become noticeably less as we reach the mountainous terrain of the Atlas Mountains to the east.

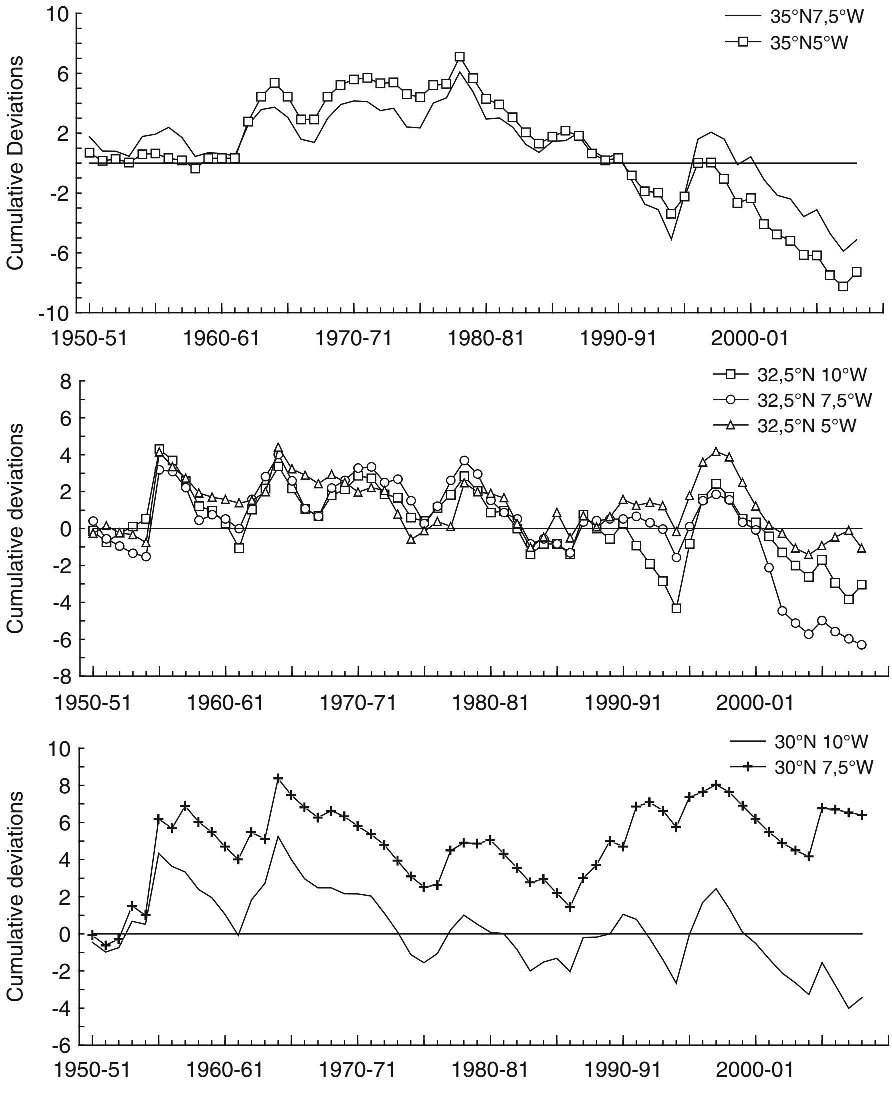


Fig. 9.3 Cumulative deviations of winter rainfall 1950–1951/2008–2009

Apart from the north and the center of our study area, where the evolution of winter precipitation shows a clear downward trend in winter rains, the south region (Fig. 9.3c) shows that this trend is less pronounced especially in the interior (30°N 7.5°W) which shows instead a succession of quite wet winters throughout the whole period. On the coast in contrast (30 ° N 10 ° W), we can see the slow decline of

Table 9.2 Average deviations from the normal of seasonal totals for the first and second sub-periods

	1950–1950/1978–1979 (%)	1979–1980/2008–2009 (%)
35°N 7.5°W	3.	−11.17
35°N 5°W	9.05	−22.67
32.5°N 10°W	2.87	−9.65
32.5°N 7.5°W	3.35	−13.11
32.5°N 5°W	1.93	−9.92
30°N 10°W	1.28	−19.48
30°N 7.5°W	2.89	−3.82

winter rains since the mid-1960s, which then gradually becomes more accentuated relatively and again from the 1980s as well. The comparison between these two periods clearly denotes in terms of rainfall the markedly deficient character of the last three decades (Table 9.2). The great weakness of the totals recorded during these winters converges significantly with those of the first period. Over the entire study period, the winter rainfall of the region decreased by an average of −7.73 % in the north, −4 % in the centre and −3.6 % in the south.

9.4 Weakly Developed Trends

In order to understand the nature of temporal discontinuities that mark our long rainfall data series, a nonparametric test (Mann-Kendall) is used as a tool of statistical validation of these discontinuities (Sneyers 1975, 1990).

$$t = \sum_{i=1}^{n} ni$$

$$E = \frac{n(n-1)}{4}$$

$$Var = \frac{n(n-1)(2n+5)}{72}$$

$$u(t) = \frac{(t-E)}{\sqrt{Var(t)}}$$

This frequently used test especially in the context of global change is considered the most appropriate method to detect any prevailing trends in climate data series (Goossens and Berger 1986). The use of this test by Rodrigo et al. (2000) distinguishes three types of changes in a series. A “tendency” refers not only to a linear change, but also a change with a maximum and a minimum at the end of the series. There is an “abrupt change” when the pattern is present with an inflection which divides the series into two series, while a “fluctuation” is generally characterized as a temporal in which a non linear temporal evolution of increasing trends and decreasing trends.

We applied this test to our data series in order to detect possible ruptures in stationarity. Thus, the sequential evolution of the Mann-Kendall test appears on Fig. 9.4 suggesting that the assumption of the existence of a dominant trend in the evolution of winter precipitation only appears to be demonstrated for the extreme north of the country. Changes in seasonal winter totals in this part denotes a decreasing trend in rainfall from the winter of 1979–1980 onwards and becomes statistically significant at the 95 % level from 1992–1993 to more in the interior areas (35°N 05°W) (Fig. 9.4b) than for the coastal areas (Fig. 9.4a). As for the rest of the grid points, both direct and retrograde curves intertwine continuously thereby demonstrating the absence of any significant trend.

This appears to be partly in agreement with the study of Norrant and Douguédroit (2006) who found no trend for monthly, seasonal and annual precipitation in the Mediterranean during the period 1950–2000. Moberg et al. (2006) spoke of an increase in winter precipitation for the period 1901–2000 in Central and Western Europe, while the trend was not significant for the same period in the Iberian Peninsula. A similar observation was noted by Gonzalez-Hidalgo et al. (2009).

The significant decrease in the cumulative seasonal winter (revealed here especially in the far north of the country) from 1979 to 1980, does, however, highlight one of the signs marking the change that has occurred within the Moroccan rainfall climate, with the introduction of seasonal episodes of recurrent droughts. The appearance from that date of some major attributes that redefined the specific features of this climate, notably the establishment of persistent deficit seasonal periods of several consecutive years during the last three decades that had never seen before. This is particularly the case in the first half of the 1980s, 1990 and 1998–1999/1999–2000, in 2001–2002, 2002–2003 and 2007–2008. The intensity of the deficit sometimes has taken on an almost exceptional and widespread character in some years, as was the case in 1982–1983 and 1994–1995.

9.5 Mode of Variability and Asymmetric Persistence of Abnormal Circulation

The variability of the large-scale atmospheric circulation is described today as an alternating sequence of movement of types or weather patterns (Casado et al. 2009). In other words, the repeated occurrence of a number of well-defined circulation patterns determines overall the general conditions in intensity and frequency of rainfall events. Atmospheric circulation in the mid-latitudes is mainly characterized by its sequence of depressions, a real pivot of atmospheric dynamics at these latitudes. The constant interaction between the synoptic wave height and surface

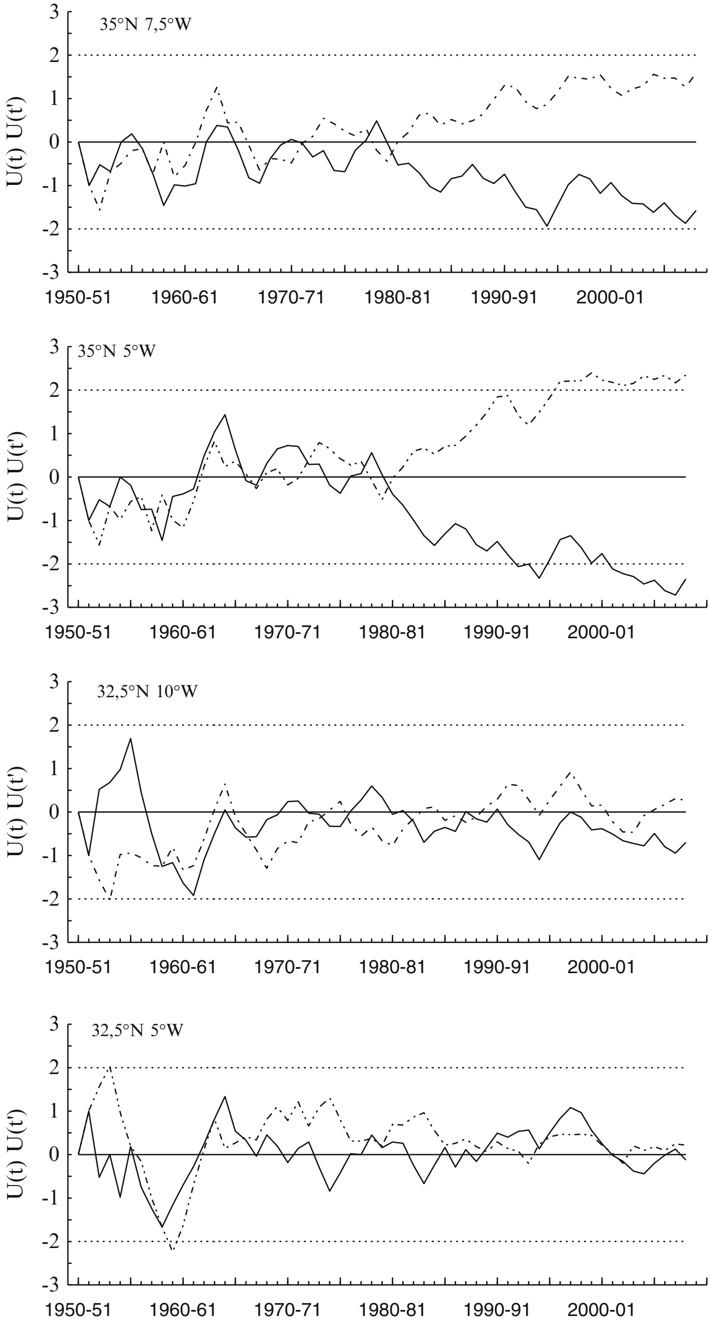


Fig. 9.4 The sequential evolution of the Mann-Kendall test 1950–1951/2008–2009

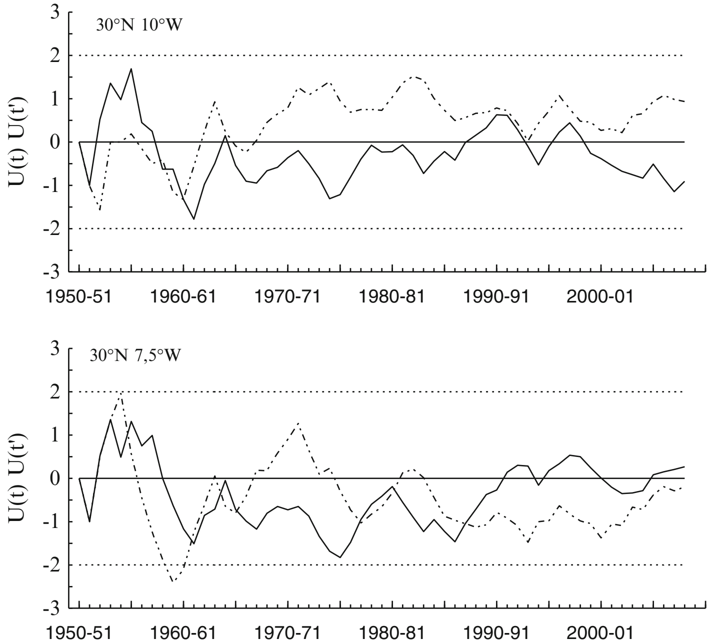


Fig. 9.4 (continued)

depressions configures overall the state and intensity of the low variability of the climate of these latitudes. This low variability often encountered in the North Atlantic is dominated by the presence of two alternating phases of the North Atlantic Oscillation, which alone explain about 40 % of the variance of the mean isobaric field of the North Atlantic (Pinto and Raible 2012). The North Atlantic Oscillation (NAO) dominates here because of its bipolar structure and spatial configuration close to our region as the most likely circulation pattern to affect the general conditions of these rainfall events and their variability in our region.

The linkages between the state of the atmospheric circulation and precipitation in the middle latitudes and the Mediterranean is now well established (Bartoly et al. 2009; Knippertz 2004; Costa et al. 2012; Lorenzo et al. 2008; Quadrelli et al. 2001; Herrera et al. 2003).

Recent studies on this type of circulation and on the predominant evolutionary trend point out an asymmetry in the persistence of these phases. Barnes and Hartman (2010) point to the fact that the NAO is linearly associated with latitudinal tilting southward and northward in the jet stream. And they stress that when the latter displays a southward movement, the circulation has more of a zonal orientation (positive phase of the NAO), and tends to stay longer than when the jet stream is moving northwards (negative phase of the NAO). The track of the depressions then follows an episodic depression according to one of the two phases of the rather zonal trajectories, and then our region is on the margins of the disturbed flow and thus suffers less favorable rainfall conditions. Otherwise, during the negative phases with rather meridian or sub-meridian pathways, more favorable conditions are felt by the receiving country which had experienced repeated frontal discontinuities of the perturbations. According to several studies of the temporal evolution of the NAO, notably Yin (2005) and McCabe et al. (2001) it was indicated that the general trend was rather to let appear a predominance of its positive phase, characterized by a northward shift of the general westerly flow and a significant reduction in the number of depressions. Another feature that also seems to be confirmed concerns the shift in its bipolar structure in recent decades (Jung et al. 2003). Thus, the two phases of the NAO have dominated asymmetrically the mid-latitude circulation conditions with a predominance of the negative phase in the 1950s and 1960s, and a predominance of the positive phase since the late 1970s and which has increased during the 1980s, 1990s and the year 2000.

It is obvious that the fluctuating variation of this major mode of circulation between the positive and negative phase is accompanied by changes in the activity of atmospheric depressions in temperate latitudes in general and the Mediterranean area in particular. The intensity, frequency and position of the track of depressions must be associated with the variation of the large-scale circulation under the influence of both internal and external forcing.

Several studies have focused on the role of the NAO in the overall variability of precipitation in the western Mediterranean in particular, including Goodess and Jones (2002), Herrera et al. (2003), Dunkheloh and Jacobeit (2003), Gonzalez Hidalgo et al. (2009), Vicente-Serrano et al. (2011), Quadrelli et al. (2001), Andrade et al. (2011), Lorenzo et al. (2008), and OrtizBevia et al. (2011).

The overall variability of precipitation according to Rodrigo and Trigo (2007) in the west part of the Mediterranean is often caused by the change in the frequency of rainfall events, or of their intensity, or a combination of both. These rainfall events are controlled by the atmospheric circulation that determines the frequency, intensity and the different orientations of the unsettled flows, which is dependent in the extra-tropical latitudes on one phase of the NAO (Santos et al. 2009).

The statistically significant relationship between Moroccan precipitation and the North Atlantic Oscillation has been highlighted by several authors including Lamb and Peppler (1987), Knippertz (2004), and Knippertz et al. (2003). They demonstrated that it is the repeated occurrence in number and intensity of the southern trajectories of low pressure systems from the Atlantic, which usually characterize the rainy winters in the north-west of Morocco. This part of Morocco is often subject to significant rainfall, when there is often a widening of the upper trough axis offshore to the coastline Ibero-Moroccan (Jacobeit 1987).

It is the study of Lamb and Peppler (1987) that was able to demonstrate the existence of a statistically significant relationship between the Moroccan precipitation for the winter period (November-April) and ONA, through the Rogers index (1984), based on the pressure difference at ground level between Ponta Delgada (Azores) and Akureyri (Iceland). The correlation coefficient describing this relationship is −0.64 for the northern part of the Atlantic coast of Morocco, and −0.57

for the southern part of the coast, explaining respectively about 41 and 32 % of the variation in rainfall in these two sectors for the period 1933–1983.

Winter precipitations are negatively correlated with the seasonal index of the NAO as shown in Table 9.3. In other words, the negative phase of this régime and the general orientation of the southern westerly flow associated with it, allows for discontinuities to reach our latitudes more easily. The correlations are much higher in the north than the south, and they are even less so towards the interior. However, the statistical link to this weather régime explains a sizeable proportion of the variation in seasonal winter totals, mainly in the north, hence the interest to see in the synoptic aspect of this relationship, the means of explaining the overall variability of our winter rainfall.

The temporal evolution of this seasonal winter NAO index (Fig. 9.5) shows almost the same two major trends identified using our rainfall data series. The period of rainy winters of 1950–1970 here coincides with the occurrence of significant negative indices, while from the 1980s and its winters with recurring deficits correspond to the predominance of positive indices.

The extreme deficit that each time has accompanied the episodes of drought which prevailed for years highlights the high variability of the climate and increases its spatio-temporal irregularity. After several decades of more or less normal rainfall during the 1950s–1970s, we have moved on to a period of uncertain and

Table 9.3 Correlations between the NAO index and winter precipitation

	NAO (djf)	% de variance
35°N07.5°W	−0.60	36.2
35°N05°W	−0.63	39.7
32.5°N10°W	−0.52	27.6
32.5°N07.5°W	−0.44	19.6
32.5°N05°W	−0.31	9.9
30°N 10°W	−0.42	17.4

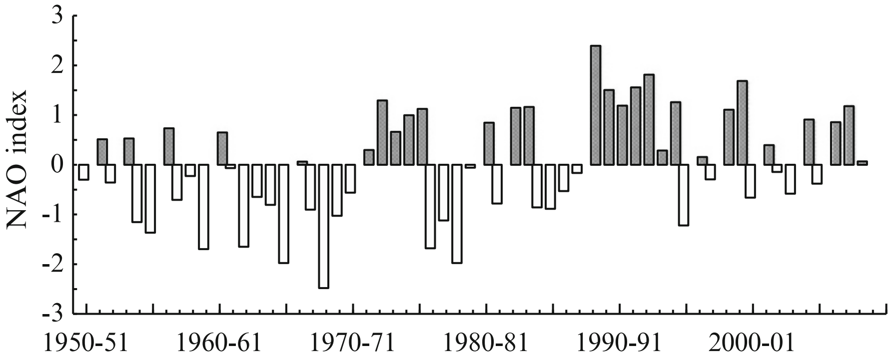


Fig. 9.5 Evolution of the winter NAO index

erratic rainfall from the 1980s. Obviously, the succession of these two periods can only be explained by the fact that they are the consequence of the strong large-scale variation of the general atmospheric circulation, which can significantly alter the precipitation conditions in our latitudes.

The occurrence of rainfall events in our region is thus dependent before anything else on the state of the atmospheric dynamics of our latitude is expressed via permanent fluctuations in the position of the high level jet stream (*eddy drive*), by which the different trajectories of the ground level perturbations (Bader and Latif 2011) with a more southerly orientation of this high level circulation that characcterizes the positioning of the negative regime of the NAO. Woollings et al. (2010) identify obviously a descent in latitude of the frontal discontinuities of the Atlantic depressions.

From a synoptic view, atmospheric conditions over the last few decades have changed remarkably as shown in the maps in Fig. 9.6 on average 500 hPa of geopotential in the first period (1950–1951/1978–1979) and during the second period (1979–1980/2008–2009).

As can be seen in Fig. 9.6a, b, the axis of the altitude ridge appears to shift slightly to the east in the middle of the second period compared to the first period. Similarly we observe a relative displacement of contours to the north during the second period. The difference between the two average situations (Fig. 9.6c shows a large zone ranging roughly from the extreme South-East of Canada to Scandinavia,

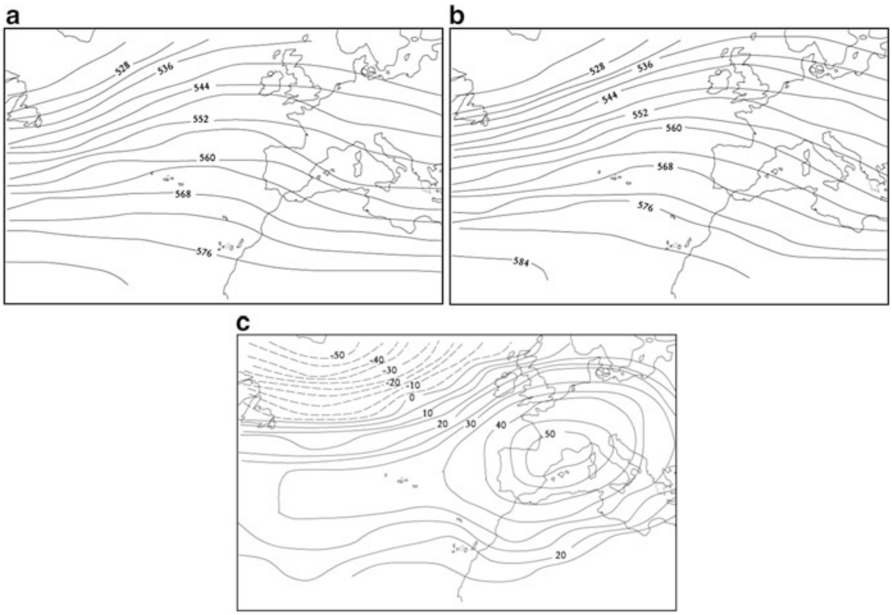


Fig. 9.6 Map of the average position of 500 hPa geopotential during the winters. (**a**) 1950–1951/1978–1979, (**b**) 1979–1980/2008–2009 and (**c**) difference (**b**) – (**a**)

where there is a level of 500 hPa geopotential during the second period, particularly in the south, which strengthens European average anticyclonic conditions.

In contrast, the contours of this level show an opposite trend to the north-west quarter of the map, which shows the widening of cyclonic conditions during the second period. Here we find again the bipolarity of the classic configuration of the NAO, with the establishment of a strong sub-meridian gradient and the relative movement of the whole structure to the north-east. This is a feature emphasized by many authors quite correctly, including Jung et al. (2003), Cassou et al. (2004), and Luo et al. (2012), as a increasingly important trend regarding the spatial configuration of the NAO, following its change of sign (Peterson et al. 2003).

Thus, the reinforcement of the global peak in Western Europe during the second sub-period of the study reached here + 50 hPa in terms of difference which explained the shifting circulation of depressions beyond the British Isles. Maintaining the trajectories of atmospheric disturbances quite some distance from our latitudes due to the repeated occurrence of the positive phases of the NAO, has led to a reduction in the number and intensity of disturbed systems following more southerly axis systems, as highlighted by Dong et al. (2011), thus giving rise to strong asymmetric and persistent anticyclonic conditions in our region.

9.6 Conclusion and Discussion

The rainfall climate of north-western Morocco on the whole is characterized by a relatively high variability, which gives it both its rather eccentric latitudinal position in relation to the general westerly flow, and its involvement in the fluctuations of large scale circulations at mid-latitudes. The very irregular rainfall of this season is then a function of the frequency of rainfall events, the degree of instability of disturbed systems and their potential rainfall.

Thus, the distribution of cumulative inter- and intra-seasonal rainfall therefore depends on the occurrence and the general orientation of the circulation depressions that primarily determine the different circulation patterns – the most predominant type in winter is the North Atlantic Oscillation.

The temporal evolution of winter accumulations gives rise to two sub-periods with contrasting rainfall. The accumulations during this season often exceeded the normal volumes in the 1950s, 1960s and 1970s, which gave its prominent character par excellence, notably its contribution to the average rainfall profile with a contribution of about 40–45 % of the annual average accumulation. The repeated occurrence of generally deficit conditions during the last three decades and a significant decrease in rainfall events during this season, has remarkably contributed to the dysfunctional character of the rainfall regime across the region. Long episodes of persistent and widespread drought in the 1980s, 1990s and 2000 were generally even more intense during the winter of those years. The accumulated volumes of winter rainfall thus decreased accordingly, mostly from 15 to 32 % compared to the first period.

The very strong variability was also reflected in an increase in extreme events that accentuates once more the strong irregularity of the rainfall climate. The year 1994–1995 for example, were extremely dry, the winter rains showed a deficit ranging across the entire region from −62.14 to −79.74 % in the north and from −100 % in the south. National cereal production has never reached the level of this year: 17,489 million quintals (CIHEAM 2006), which led the government to declare for the first time this year as "a year of national disaster". For the following year 1995–1996, the winter season was extremely wet, with the difference from the normal reaching values everywhere ranging from +56.33 to +120 % in the north and from +68.64 to +187.4 % in the centre and around 200 % in the south. Domestic production of grain during that year recorded a record of more than 99,822 million quintals (CIHEAM 2006).

The decreasing contribution of winter precipitation directly affects the water balance and worsens the situation of water availability, making it more difficult to engage work proactively in a process of sustainable development. The effort required for adaptation must confront continually towards constructing a permanent equilibrium between managing scarcity, environmental conservation, and development imperatives. Persistent drought over several years in a row remains a major constraint with multiple agricultural, hydrological and socio-economic consequences.

The trend observed in the rainfall climate of the region is linked to changing weather conditions on a large scale that have occurred since the 1980s in extra-tropical space of the North Atlantic. On the one hand, the predominant occurrence of a high NAO index has had an effect on the maintenance of circulation depressions further north. Interaction with the ENSO phenomenon has been recognized as the cause of global climate variability (Sterl et al. 2007; Trenberth et al. 1998) and the increased frequency and intensity of recent decades are considered potentially attributable to global warming (L'heureux et al. 2013), and these on the other hand are factors forcing atmospheric dynamics that may give rise to very intense and persistent climate anomalies.

According to the latest IPCC report of 2007 and based on the different model projections of low resolution (Solomon et al. 2007), Morocco would experience a significant reduction in rainfall by the end of the century. This decrease is due in large part, according to the report, of the inreasing frequency also of positive phases of the NAO among other factors, which is associated with the increase in latitude of the trajectories of disturbances on the polar front, and the sustained persistence of strong anticyclonic anomalies on our country.

References

Andrade, C., Santos, J. A., Pinto, J. G., & Real, J. C. (2011). Large – Scale atmospheric dynamics of the wet winter 2009–2010 and its impact on hydrology in Portugal. *Climate Research, 46*, 29–41.

Bader, J., & Latif, M. (2011). Winter jet stream trends over the Northern hemisphere. *Climate Dynamics, 36*, 463–472.

Barnes, E., & Hartman, D. L. (2010). Dynamical feedbacks and the persistence of the NAO. *Journal of Atmospheric Science, 67*, 851–865.

Barnston, A., & Livezey, R. E. (1987). Classification, seasonality and persistence of low frequency atmospheric circulation patterns. *Monthly Weather Review, 115*, 1083–1126.

Bartoly, J., Pongracz, R., & Pattantyus-Abrham, M. (2009). Analyzing the genesis, intensity and tracks of western Mediterranean cyclones. *Theoretical and Applied Climatology, 96*, 133–144.

Casado, M. J., Pastor, F. J., & Doblas-Reyes, F. J. (2009). Euro – Atlantic circulation types and modes of variability in winter. *Theoretical and Applied Climatology, 96*, 17–29.

Cassou, C. (2008, September 25). Intraseasonal interaction between the Madden– Julian Oscillation and the North Atlantic Oscillation. *Nature* 455. doi:10.1038/nature07286.

Cassou, C., Terray, L., Hurrell, J. W., & Deser, C. (2004). North Atlantic winter climate regimes: Spatial asymmetry, stationarity with time, and oceanic forcing. *Journal of Climate, 17*, 1055–1068.

Centre International des Hautes Etudes Agronomiques Mediterranéennes (CIHEAM). (2006). *Les notes d'analyse du CIHEAM N°7* (24 p) Mars 2006. Institut Agronomique Méditerranéen de Montpellier – France

Costa, A. C., Santos, J. A., & Pinto, J. G. (2012). Climate change scenario for precipitation extremes in Portugal. *Theoretical and Applied Climatology, 108*, 217–234.

Dong, B., Sulton, R. T., & Woollings, T. (2011). Changes of interannual NAO variability in response to greenhouse gases forcing. *Climate Dynamics, 37*, 1621–1641.

Dunkheloh, A., & Jacobeit, J. (2003). Circulation dynamics of Mediterranean precipitation variability 1948–98. *International Journal of Climatology, 23*, 1843–1866.

Garcia–Barron, L., Aguilar, M., & Sousa, A. (2011). Evolution of annual rainfall irregularity in the southwest of Iberian Peninsula. *Theoretical and Applied Climatology, 103*, 13–26.

Gonzalez–Hidalgo, J. C., Lopez–Bustins, J. A., Stepanek, P., Martin–Vide, J., & de Luis, M. (2009). Monthly precipitation trends on the Mediterranean fringe of the Iberian Peninsula during the second-half of the twentieth century (1951–2000). *International Journal of Climatology, 29*, 1415–1429.

Goodess, C. M., & Jones, P. D. (2002). Links between circulation and changes in the characteristics of Iberian rainfall. *International Journal of Climatology, 22*, 1593–1615.

Goossens. C., & Berger, A. (1986). Annual and seasonal climatic variations over the northern hemispheric and Europe during the last century. *Annales Geophysicae*, *86/04 B,* 385–399.

Haylock, M. R., & Goodess, C. M. (2004). Interannual variability of European extreme winter rainfall and links with mean large – Scale circulation. *International Journal of Climatology, 24*, 759–776.

Herrera, R. G., Gallego, D., Hernandez, E., Gimeno, L., Ribero, P., & Calvo, N. (2003). Precipitation trends in the Canary. *International Journal of Climatology, 23*, 235–241.

Hurrell, J. W. (1995). Decadal trends in the north Atlantic oscillation: Regional temperature and precipitation. *Science, 269*, 676–679.

Hurrell, J. W., & Deser, C. (2009). North Atlantic climate variability: The role of the north Atlantic oscillation. *Journal of Marine Systems, 78*, 28–41.

Jacobeit, J. (1987). Variations of trough positions and precipitation pattern in the Mediterranean area. *International Journal of Climatology, 7*, 453–476.

Jung, T., Himler, M., Ruprecht, M., Kleppek, E., Gulev, S. K., & Zolina, O. (2003). Characteristics of the recent Eastward shift of interannual NAO variability. *Journal of Climate, 16*, 3371–3382.

Knippertz, P. (2004). A simple identification scheme for upper-level troughs and its application to winter precipitation variability in Northwest Africa. *Journal of Climate, 17*, 1411–1418.

Knippertz, P., Christoph, M., & Speth, P. (2003). Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates. *Meteorology and Atmospheric Physics, 83*, 67–88.

Kucharski, F., & Molteri, F. (2003). On the linearities in a forced North Atlantic Oscillation. *Climate Dynamics, 21*, 677–687.

Kvamto, N. G., Song, Y., Seierstas, I. A., Sortrberg, A., & Stephenson, D. B. (2008). Clustering of cyclones in the Arpege general circulation model. *Tellus A, 60*, 547–556.

L'heureux, M. L., Collins, D. C., & Hu, Z. Z. (2013). Linear trends in sea surface temperature of the tropical Pacific ocean and implications for the El Nino – Southern Oscillation. *Climate Dynamics, 40*, 1223–1236.

Lamb, P., & Peppler, R. A. (1987). North Atlantic oscillation: Concept and application. *Bulletin of American Meteorological Society, 10*, 1217–1225.

Lorenzo, M. N., Taboada, J. J., & Gimeno, L. (2008). Links between circulation weather types and teleconnection patterns and their influence on precipitation patterns in Galicia (NW Spain). *International Journal of Climatology, 28*, 1493–1505.

Luo, D., Cha, J., & Feldstein, S. B. (2012). Weather regime transition and interannual variability of the North Atlantic Oscillation. Part I: A likely connection. *Journal of Atmospheric Science, 69*, 2329–2346.

Martin-Vide, J., & Lopez-Bustins, J. A. (2006). The Western Mediterranean Oscillation and rainfall in the Iberian Peninsula. *International Journal of Climatology, 26*, 1455–1475.

McCabe, G. C., Clark, M. P., & Serrze, M. C. (2001). Trends in Northern hemisphere surface cyclone frequency and intensity. *Journal of Climate, 14*, 2763–2768.

Michelangeli, P. A., Vautard, R., & Legras, B. (1995). Weather regimes: Recurrence and quasi stationarity. *Journal of Atmospheric Science, 52*, 1237–1256.

Moberg, A., Jones, Ph. D., Lister, D., Walther, A., Brunet, M., Jacobeit, J., Alexander, L.V., Della-Marta, P. M., Luterbacher, J., Yiou, P., Chen, D., Albert, M,. Klein Tank, A. G., Saladié, O., Sigró, J., Aguilar, E,. Alexandersson, H., Carlos Almarza, C., Auer, I., Barriendos, M., Begert, M., Bergström, H., Böhm, R., Butler, C. J., Caesar, J., Drebs, A., Founda, D., Gerstengarbe, F. W., Micela, G., Maugeri, M., Österle, H., Pandzic, K., Petrakis, M., Srnec, L., Tolasz, R., Tuomenvirta, H., Werner, P. C., Linderholm, H., Philipp, A., Wanner, H., & Xoplaki, E. (2006). Indices for daily temperature and precipitation extremes in Europe analyzes for period 1901–2000. *Journal of Geophysical Research, 111,* D22106. doi:10.1029/2006JD007103.

Norrant, C., & Douguedroit, A. (2006). Monthly and daily precipitation trends in the Mediterranean (1950–2000). *Theoretical and Applied Climatology, 83*, 89–106.

OrtizBevia, M. J., Sanchez-Gomez, E., & Garcia, J. A. (2011). North Atlantic atmospheric regimes and winter extremes in the Iberian Peninsula. *Natural Hazards and Earth System Science, 11*, 971–980.

Peterson, K. A., Lu, J., & Greatbatch, R. J. (2003). Evidence of nonlinear dynamics in the eastward shift of the NAO. *Geophysical Research Letters, 30*(2), 1030. doi:10.1029/2002GL015585.

Pinto, J. G., & Raible, C. C. (2012). Past and recent changes in the North Atlantic Oscillation. *Wires Climate Change, 3*, 79–90.

Plaut, G., & Simonnet, E. (2001). Large-scale circulation classification, weather regimes, and local climate over France, the Alps and Western Europe. *Climate Research, 17*, 303–324.

Quadrelli, R., Pavan, V., & Molteni, F. (2001). Wintertime variability of Mediterranean precipitation and its links with large – Scale circulation anomalies. *Climate Dynamics, 17*, 457–466.

Rodrigo, F. S., & Trigo, R. M. (2007). Trends in daily rainfall in the Iberian Peninsula from 1951 to 2002. *International Journal of Climatology, 27*, 513–529.

Rodrigo, F. S., Esteban–Para, M. J., Pozo–Vasquez, D., & Castro–Diaz, Y. (2000). Rainfall variability in southern Spain on decadal to centennial times scales. *International Journal of Climatology, 20*, 721–732.

Rodriguez–Fonseca, Polo, I., Serrano, E., & Castro, M. (2006). Evaluation of the North Atlantic SST forcing on the European and northern African winter climate. *International Journal of Climatology, 26*, 179–191.

Rogers, J. C. (1984). The association between the North Atlantic Oscillation and the southern Oscillation in the Northern Hemisphere. *Monthly Weather Review, 112*, 1999–2015.

Santos, J. A., Andrade, C., Corte–Real, J., & Leite, S. (2009). The role of large scale eddies in the occurrence of winter precipitation deficits in Portugal. *International Journal of Climatology, 29*, 1493–1507.

Shabbar, A., Huang, J., & Higuchi, K. (2001). The relationship between the wintertime North Atlantic Oscillation and blocking episodes in the North Atlantic. *International Journal of Climatology, 21*, 355–362.

Sneyers, R. (1975). Sur l'analyse statistique des séries d'observations. *Note technique de l'OMM n° 143*.

Sneyers, R. (1990). On the statistical analysis of series of observation. *WMO, Technical Note n° 143,* Genève.

Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M. M. B., & Miller, H. L. (2007). *Climate Change 2007 The physical science basis*. New York: Cambridge University Press.

Sterl, A., Oldenborgh, G. J. V., Hazeleger, W., & Burgers, G. (2007). On the robustness of Enso teleconnections. *Climate Dynamics, 29*, 469–485.

Trenberth, K. E., Branstator, G. W., Karoly, D., Kumar, A., Lau, N., & Ropelewski, C. (1998). Progress during TOGA in understanding and modelling global teleconnections associated with tropical sea surface temperatures. *Journal of Geophysical Reseach, 103*, 14 291–14 324.

Trigo, R. M., Osbon, T. J., & Corte–Real, J. M. (2002). The North Atlantic oscillation influence on Europe: Climate impacts and associated physical mechanisms. *Climate Research, 20*, 9–17.

Vautard, R. (1990). Multiple weather regimes over the North Atlantic: Analysis of Precursors and Successors. *Monthly weather Review*, *118*, 2056–2081.

Vicente-Serrano, S. M., Trigo, R. M., López-Moreno, J. I., Liberato, M. L. R., Lorenzo-Lacruz, J., Beguería, S., Morán-Tejeda, E., & Kenawy, A. (2011). Extreme winter precipitation in the Iberian Peninsula in 2010: Anomalies, driving mechanisms and future projections. *Climate Research, 46*, 51–65.

Woollings, T., Hannachi, A., & Hoskins, B. (2010). Variability of the North Atlantic eddy– Driven jet stream. *Quarterly Journal of Royal Meteorological Society, 136*, 856–868.

Yin, J. H. (2005). A consistent poleward shift of the storm tracks in simulations of 21st century climate. *Geophysical Research Letters, 32*, L18701. doi:10.1029/2005GL023684.

Ali Bellichi holds a PhD in Climatology from the University of Aix–Marseille II, France, as well as a PhD in Climatology from the University of Liege, Belgium. He is currently a professor at the University of Mohamed V, Rabat. Morocco. His main research interests are Climate variability and global change, Atmospheric circulation, Weather regimes (North Atlantic), Moroccan climate, Enso regulation and Teleconnection.

Chapter 10
Projections of Peanut Yields from 2011 to 2040 in Senegal Using Classification and Regression Trees

Mamadou Adama Sarr, Ousmane Seidou, Christopher R. Bryant, and Angelina Amadou

Abstract Despite the obvious and significant impacts of climate change and variability on crop yields in the Sahel during the past three decades, few quantitative works on potential climate change impacts on Sahelian agriculture has been conducted. Hence, this chapter presents results of predictive statistical models of peanut yields in Diourbel (Senegal) for the period 2011–2040. Rainfall indices were used as input data for a Classification and Regression Tree (CART) model aimed at forecasting the level of yield which was broken into three classes (normal, above normal, below normal). Cumulative seasonal rainfall, the percentage of days with rain, the maximum cumulative precipitation on three consecutive days, the maximum number of consecutive dry days, the maximum consecutive days of precipitation, the average precipitation intensity by wet days and the 95th percentile of daily precipitation were used to describe rainy season characteristics. The model was successfully calibrated and validated over a control period (1997–2007), then driven by the downscaled projected precipitations of six Regional Circulation Models (RCMs). These RCMs were driven by two Global Circulation Models (GCMs) under the SRES A1B scenario (AMMA-SETS). Two types of downscaling

M.A. Sarr (✉)
Université de Montréal (Québec, Canada) and Centre de Suivi Écologique (Dakar, Senegal), Dakar, Senegal
e-mail: mamadou_sarr74@hotmail.com; adama.sarr@cse.sn

O. Seidou
University of Ottawa, ON, Canada
e-mail: oseidou@uottawa.ca

C.R. Bryant
University of Montréal, Montréal, QC, Canada

School of Environmental Design and Rural Planning, University of Guelph, Guelph, ON, Canada
e-mail: christopher.robin.bryant@gmail.com

A. Amadou
Department of Physics and Astronomy, Howard University, Washington, DC, USA
e-mail: angelinaamadou@gmail.com

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_10

techniques were taken into consideration for the outputs of RCMs (multiple regression and Quantile-Quantile transformation). Eventually, the corrected DMI-HIRHAM5 model was selected, and corrected outputs were used to generate predictors for the CART model for the period 2011–2040. These predictors were then used to estimate future results in Diourbel. The results show yields were split between high and low normal levels for the next 30 years.

Keywords Rainfall indices • Peanut yields • Regional climate model • Classification and regression tree model • Senegal

10.1 Introduction

Global mean temperature increase in recent decades has undoubtedly produced numerous environmental impacts worldwide (FAO 2008; World Bank 2009). Specifically, amongst the different continents, Africa remains the most exposed to negative climate change impacts due to several socio-economic and environmental factors (Conway 2011; Zeng 2003). Reducing vulnerability associated with climate change has become a major concern for the Sahel region given the close relationship between climate, agricultural activities (including livestock) and population well-being (health, food safety, drinking water supply). Additionally, recent and projected climatic shifts are presently part of the prevailing challenges African policy makers will have to tackle (IPCC 2007; Wood 2008). In Senegal particularly, most sectors of the agricultural industry (including peanut production) are heavily dependent on rainfall. Moreover, agriculture is a key sector of the economy that provides employment for 72.4 % of the labour force in the primary sector and contributed up to 20.8 % of GDP in 2010: 10.6 % for agriculture, 7.6 % for livestock and 2.1 % for fishing (ANSD, 2011). Crucial and strategic to the entire economy of numerous nations, agriculture is often cited as an example of activity that is highly reliant directly or indirectly upon climatic conditions (Parry et al. 2004; Rosenzweig et al. 1993). Any changes in the global climate system, as projected by various Global Circulation Models (GCMs) or Regional Circulation Models (RCMs), will result in changes in global agricultural production including changes in crop yields and, to a lesser extent, cultivated areas. It is obvious that maintaining adequate agricultural production which may fulfill the food needs of the world population is essential for the political, economic and social stability of present and future generations (Reid et al. 2006). From that perspective, agricultural yields provide a primary measurement of vulnerability to climate change. In this chapter, a statistical model for the prediction of peanut yields in Diourbel, a region of Senegal (Fig. 10.1) is developed. The model output is categorical: based on rainfall indices, it predicts whether peanut yield is above normal, normal or below normal.

10.2 Methodology

10.2.1 Classification and Regression Trees

A Classification and Regression Tree (CART) is a classification method that uses historical data to build a descriptive and predictive model of a relationship between a set of predictors and a categorical variable (Salford-Systems 2001). Its algorithm consists of traveling along a tree by answering 'true' or 'false' type questions regarding the value of a predictor whenever a node is encountered (Breiman et al. 1984). At the end of the tree, an estimate of the variable is obtained for prediction. The tree is built with a set of calibration data and validated with an independent data set. During calibration, the CART algorithm searches for all possible variables with all possible values in order to find the best distribution which is the query that splits the data into two parts with an optimum homogeneity. The procedure is repeated for each partition of data until the partition is uniform, or even smaller than a user preset threshold size. The techniques aforementioned feature a tree visualization convenience and can easily be described using normal language.

10.2.2 Data

Precipitation indices are predictors that are commonly used to describe the characteristics of a rainy season (Bourgouin 2000; Cheng et al. 2004). The indices used for this study were selected to reflect the occurrence and duration of wet and dry spells, and the average intensity of rain, and wet days of the most intense and extreme precipitation (Table 10.1). These indices are widely used internationally by research groups and task forces such as the Expert Team on Climate Change Detection Monitoring and Indices (ETCCDMI) (Booth et al. 2011), or the STARDEX (Statistical and Regional Dynamical Downscaling of Extremes for European Regions) team (Chauvin and Denvil 2007).

Two types of daily precipitation data are used to generate the indices:

(a) Regional averages (average of stations by region; Fig. 10.1) during the rainy season from June to October (1997–2007)
(b) Simulated precipitation (two stations in the study area: 1997–2050) by six regional circulation models from the experience of AMMA-ENSEMBLES (Table 10.2). AMMA-ENSEMBLES is an international collaborative model intercomparison experiment (Paeth et al. 2011) that results into a set of regional climate model (RCM) simulations covering most of the African continent at a resolution of 50 km. The RCMs are driven by either the ERA-INTERIM reanalysis, or by global climate models outputs simulated under the SRES A1B emission scenarios. The data sets are available for free in the experiments of the online database (http://ensemblesrt3.dmi.dk/).

Table 10.1 Description of the characteristics of rainfall indices used

Acronym	Description [unit]
Prcp1	Frequency – days of rain (precipitation ≥1 mm) [%]
R3d	Extreme – maximum of 3 days with precipitation [mm]
CDD	Frequency – maximum consecutive dry days (precipitation <1 mm) [day]
CWD	Frequency – maximum consecutive days of rainfall (precipitation >= 1 mm) [day]
SDII	Intensity – intensity of precipitation (rain/rainy day) [mm/day]
Prptot	Total seasonal rainfall (rainfall >= 1 mm) [mm]
R95p	Extreme – 95th percentile of daily precipitation [mm/day]

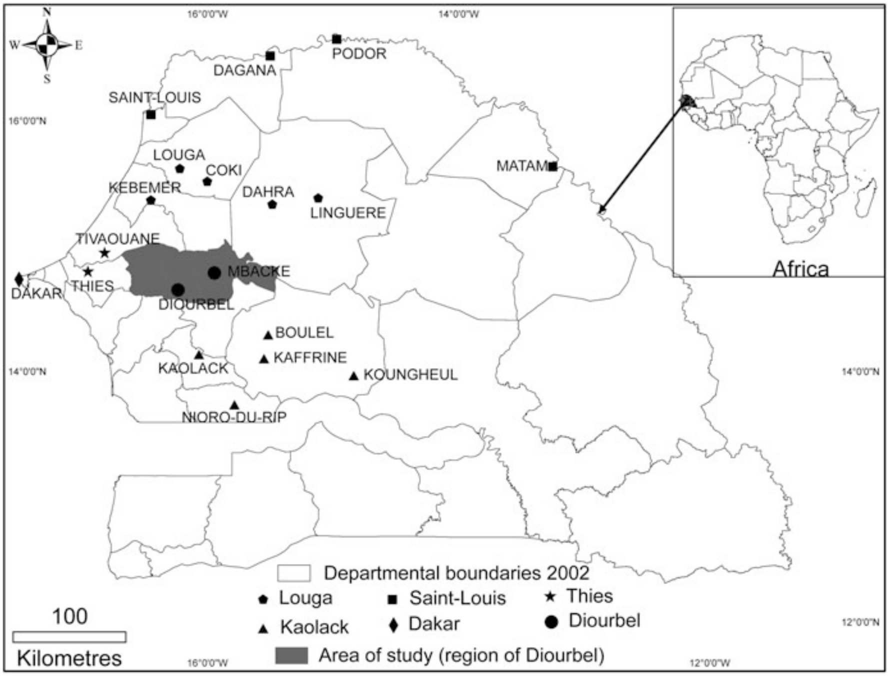


Fig. 10.1 Map of the study area: administrative region of Diourbel in grey and stations used to generate average regional indices (5 regions for calibration and Diourbel for validation)

Peanut yields were downloaded from a website operated by the Food and Agriculture Organization (www.countrystat.org) for the time period 1997–2007 for the six regions considered: five regions for calibration and Diourbel for validation. The observed yields are split into three equal groups (below normal, normal, above normal), each having the same probability of occurrence. The three classes are coded 1, 2 and 3 in the model: a yield of less than 0.45 ton per hectare (below normal), a yield between 0.65 and 0.45 ton per hectare (normal) and a yield greater than 0.65 ton per hectare (above normal) performance.

Table 10.2 Description of 6 regional circulation models (AMMA-ENSEMBLES)

Institution	GCM	RCM	Acronym
KNMI (Royal Netherlands Meteorological Institute, Netherlands)	ECHAM5-r3	RACMO	KNMI-RACMO2
DMI (Danish Meteorological Institute)	ECHAM5-r3	HIRHAM	DMI-HIRHAM5
ICTP (Abdus Salam International Centre for Theoretical Physics, Italy)	ECHAM5-r3	RegCM	ICTP-REGCM3
METNO (Norwegian Service Centre for Climate Modelling, Norway)	HadCM3Q0	HIRHAM	METNOHIRHAM
HC (Met Office, UK)	HadCM3Q0	HadRM3P	METO-HC_HadRM3.0
INM (Instituto Nacional de Meteorologica, Spain)	HadCM3Q0	RCA	INMRCA3

10.2.3 RCMs Daily Precipitation Correction

Temporal and probability distributions of daily precipitation simulated by climate models are known to differ from reality, thus resulting in biases in rainfall indices if directly used (Fronzek and Carter 2007). In order to reduce the biases, two downscaling methods are used to correct the daily distributions of model precipitation. The first downscaling method is the Automated Statistical Downscaling (ASD) which uses GCM/RCM outputs as predictors, and observed precipitation (Guo Jing et al. 2012; Messami et al. 2008). Once calibrated and validated, the ASD model will generate future precipitation whose statistical characteristics are different from the statistical characteristics of the raw model output and closer to those of observed data. The second downscaling technique is the Quantile-Quantile transformation (Maraun et al. 2010; Themeßl et al. 2011). The process involves finding a function of empirical transfer in such a way that after transformation, the probability distribution of model outputs is identical to the observations for the historical period.

This transformation can be written as:

$$P_{transforme} = F^{-1}_{observations}(F_{RCM}(P_{RCM}))$$

$P_{transformé}$ is the precipitation corrected by Quantile-Quantile (QQ), P_{RCM} is the precipitation from the models, F_{RCM} is the empirical cumulative distribution function of RCM-simulated precipitation over the control period and $F^{-1}_{observations}$ is the reciprocal of the cumulative distribution function of the observations.

Once corrections are made with ASD and QQ, the rainfall index is computed for the historical period using observations, raw output of RCMs and outputs of the transformed RCMs.

Four boxplots are generated for each rainfall index: using the time series of the index calculated with observations (OBS), using the time series of the index calculated with uncorrected RCM outputs (RAW-RCM), using the time series of the index calculated with QQ-corrected RCM outputs (OBS), and finally using the time series of the index calculated with ASD-corrected RCM outputs (OBS). The boxplots are presented on Fig. 10.2 and used to assess which time series of indices has more similarity to actual observations. It can be seen that in all cases, ASD or QQ provide a more reasonable estimation of the indice than the raw output of the RCM. The best transformation depends of the rainfall indice being considered. The QQ transformation was preferred for all indices compared with ASD.

10.2.4 Calibration and Validation of the Yield Model

Calibration and validation are based on a total of 66 values comprising the mean values of indices and yields of six regions between 1997 and 2007: Dakar, Diourbel, Louga, St. Louis, Thies and Kaolack (Fig. 10.1). This particular choice is due to the fact that there are only 10 years of available yield data at each station, which necessitated using several stations in the same region in order to have a series that is long enough for the model. The CART model was calibrated with 55 values (Dakar, Louga, St. Louis, Thies and Kaolack) and validated with 11 (Diourbel). Figure 10.3 shows the resulting CART tree. The tree allows us to visualize that above normal yields can be expected when there are than 21.2 % of rainy days during the rainy season. When there are less than 21.2 % of rainy days in the rainy season, the outcome is driven by the average wet day intensity (SDII) and the length of the dry season (CDD), as shown on Fig. 10.3.

As shown in nodes 1–5, future assessment of annual peanut yield in Diourbel region is extremely sensitive to the frequency and intensity values of indices such as Prep1, SDII and CDD. The calibration of the model was deemed satisfactory as predicted values were equal to simulated values 41 times out of 55 on the calibration data set and seven out of ten times in the validation data set (Table 10.3). Therefore, it was decided to proceed with the analysis and use the indices calculated with downscaled corrected future precipitation as inputs to the CART model.

10.2.5 Yields Projection

During this process, six model outputs were corrected using the ASD and QQ methods: Table 10.4 shows the best transformations by indicator and model.

After visual analysis of Fig. 10.2, the DMI-HIRHAM5 model was chosen to calculate future rainfall indices. The QQ transformation was used for all indices except CDD for which better results were achieved using the raw outputs from the RCM were. Subsequently, future estimates of peanut yields were generated with the

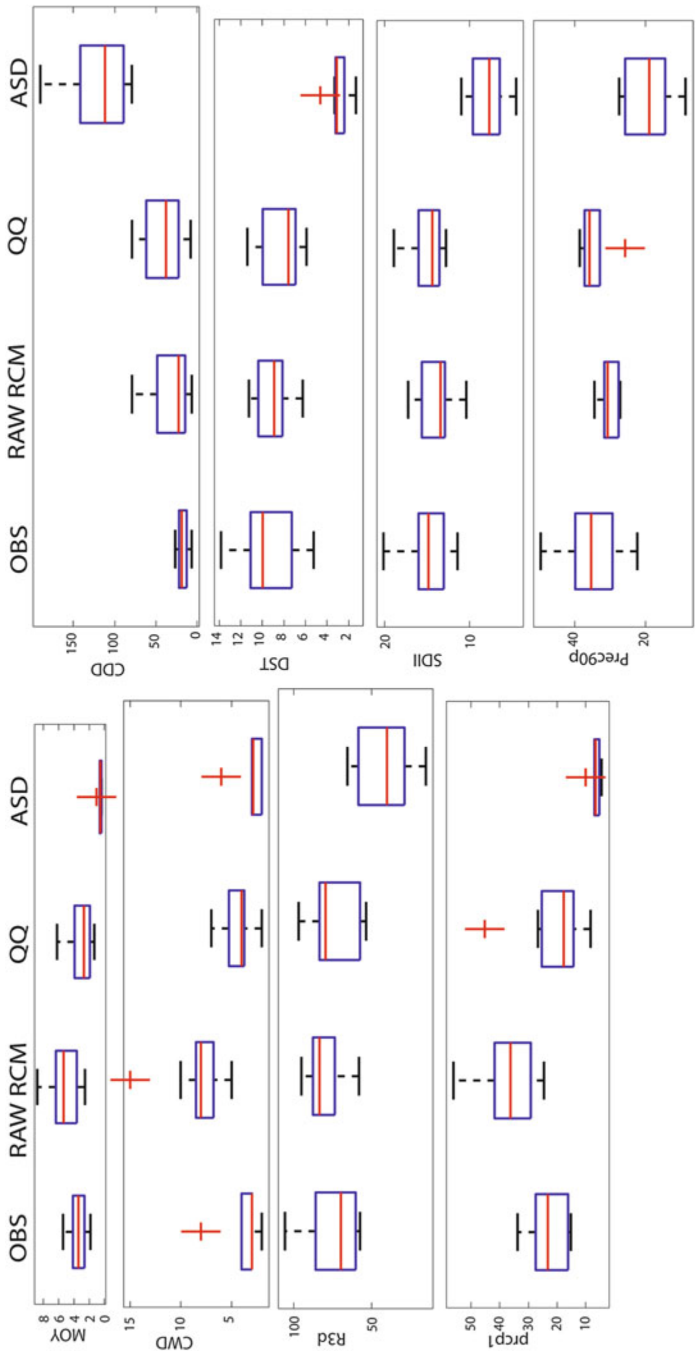


Fig. 10.2 Diagram of seasonal averages (Diourbel and Manzano for the study area) for each index according to the raw RCM output, by ASD application and the QQ

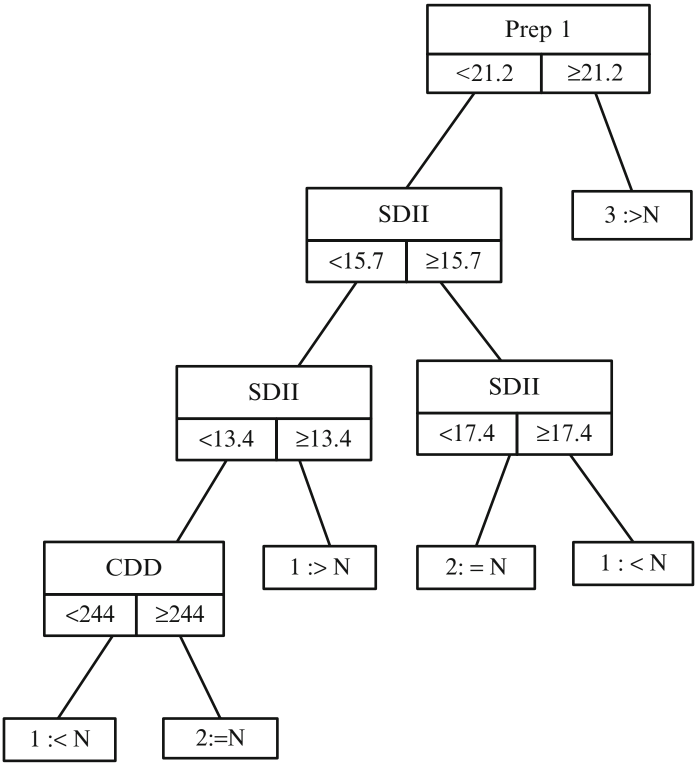


Fig. 10.3 Classification tree using the CART calibration (for 1997–2007). *N* normal

Table 10.3 The CART model validation (1997–2007)

Categorical yields observed	1	3	3	3	3	1	2	1	3	1	1
Categorical yields predicted	3	1	3	3	3	1	3	1	3	3	1

1: less than normal; 2: normal and 3: greater than normal. In some columns, the same values were observed as predicted (Diourbel region)

calibrated CART model, and plotted on Fig. 10.4. There is approximately the same number of deficit and surplus years. However, the yield deficit phase appears to be longer (e.g. succession of 4 years such as 2015–2018 and 2031–2034).

10.3 Discussion

Results obtained on peanut yields for the future period (2011–2040), far from being absolute yields provide information on annual trends as related to normal values (1997–2007). Additionally, the statistical model predicts an alternance of years

Table 10.4 Identification of the correction method closest to observations depending on rainfall and climate (DMI-HIRHAM5)

		DMI-HIRHAM5	INMRCA3	METO-HC	ICTP-REGCM3	UCLM	KNMI-RACMO2.2b
Mbacké	**CDD**	S.B.-MRC[a]	QQ	G.O. – RCM	G.O. – RCM	G.O. – RCM	G.O. – RCM
	CWD	QQ	QQ	QQ	QQ	QQ	ASD
	R3D	QQ	G.O. – RCM	ASD	ASD	ASD	ASD
	SDII	QQ	QQ	ASD	ASD	ASD	ASD
	Prcp1	QQ	QQ	G.O. – RCM	QQ	QQ	G.O. – RCM
Diourbel	**CDD**	QQ	QQ	G.O. – RCM	QQ	G.O. – RCM	G.O. – RCM
	CWD	QQ	ASD	QQ	QQ	QQ	QQ
	R3D	S.B.-MRC	ASD	ASD	ASD	QQ	QQ
	SDII	S.B.-MRC	ASD	ASD	ASD	QQ	QQ
	Prcp1	QQ	G.O. – RCM	G.O. – RCM	QQ	ASD	QQ

G.O. – RCM
[a]Gross output of Regional Circulation Models

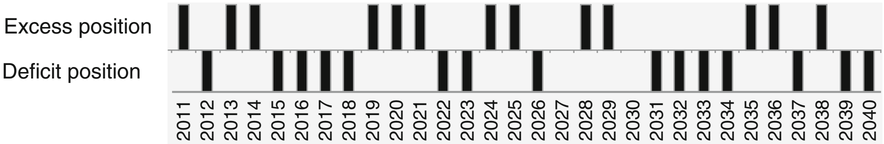


Fig. 10.4 Variations of the projected peanut yields for the 2011–2040 periods

with deficit yields and years with a yield excess. There are slightly more years with a deficit (15) than years with excess precipitation (13), suggesting that yields in the future may be on average lower than present yields. However, one has to keep in mind that several factors are not taken into account in the simple model developed in these analyses. Factors that are not accounted for include management factors, possible changes in technology, soil conditions or in the cultivar being used. The conclusion is also only valid for the climate scenario used, therefore the interpretation of results has to acknowledge the uncertainty in climate models predictions (Fronzek and Carter 2007; Treut et al. 2007).

Another limitation of the statistical or empirical approach is that it takes into account only a static description of the existing relations between the groundnut crop yields and climatic conditions (i.e. the indices used) for Diourbel region. The results of the regression analysis do not explicitly provide the way that one of the climate indices such as SDII or CDD affects the variable performance of peanuts. At the same time, those results do not provide an explanation of the mechanisms that underlie the relationship between agro climatic indices and yields (Poluektov and Topaj 2001). Agriculture in Sahelian countries in general and in Senegal in particular relies heavily on the random nature of rainfall but also includes social and economic practices (e.g. agricultural labour, agricultural practices, and domestic and foreign markets…) that directly or indirectly influence yields, which are not included in this method. The use of such a statistical approach is supported in this case by the lack of the necessary data to move towards a biophysical approach that would analyze the causal relationships between variables. However, the results can give elements of variability and the trend of future returns related to the most critical climate indices.

10.4 Conclusion

In this chapter, a CART (Classification and Regression Tree) model of peanut yields has been calibrated and validated for the Diourbel region in Senegal. The data input are rainfall indices such as the days of rain (Prcp1), the maximum of 3 days with precipitation (R3d), the maximum number of consecutive dry days (CDD), the maximum number of consecutive days of rainfall (CWD), the intensity of precipitation (SDII), the total seasonal rainfall (Prptot) and the 95th percentile of daily precipitation (R95p). The statistical model predicted a higher yield deficit than normal. The statistical approach used has some limitations that must be taken into account to better understand and interpret the results. The model provides a static description of the relationships between dependent variables (yields) and explanatory variables (rainfall indices) for a given site. Furthermore, this technique lacks a deeper understanding of the connection between climate indices or agro-climate effects (Thornley and Johnson 2000; Poluektov and Topaj 2001). It is important to mention that the yield prediction model cannot evaluate the impact of climate change on agriculture without taking into account the socio-economic aspects related to agriculture (De Bruin 2011; Tacoli 2011). Even though this present study, based on objective criteria, chooses a scenario model and a correction method, it is nevertheless advisable to use a larger number of climate scenarios in order to achieve broader and more diverse situations. In conclusion, the findings of this study should be used primarily in decision making processes aimed at improving the farmer's capacity to adapt and not in debates on absolute values.

References

Agence Nationale des Statistiques et de la Démographie. (2011). Situation économique et sociale du Sénégal. *République du Sénégal*. Ministère de l'économie et des Finances.

Booth, E. L. J., Byrne, J. M., & Johnson, D. L. (2011). Climatic changes in western North America, 1950–2005. *International Journal of Climatology, 32*(15), 2283–2300

Bourgouin, P. (2000). A method to determine precipitation types. *Weather and Forecasting, 15*(5), 583–592.

Breiman, L., Friedman, J. H., Olshen, R. A., & Stone, C. J. (1984). *Classification and regression trees* (p. 358). Boca Raton, Florida, U.S.A.: Chapman and Hall/CRC Press.

Chauvin, F., & Denvil, S. (2007). Changes in severe indices as simulated by two French coupled global climate models. *Global and Planetary Change, 57*(1–2), 96–117.

Cheng, C. S., Auld, H., Li, G., Klaassen, J., Tugwood, B., & Li, Q. (2004). An automated synoptic typing procedure to predict freezing rain: An application to Ottawa, Ontario, Canada. *Weather and Forecasting, 19*(4), 751–768.

Conway, D. (2011). Adapting climate research for development in Africa. *Wiley Interdisciplinary Reviews: Climate Change, 2*(3), 428–450.

De Bruin, K. (2011). *An economic analysis of adaptation to climate change under uncertainty. English*. Wageningen: Wageningen Universiteit (Wageningen University).

FAO. (2008). *Climate change, water and food security*. Rome: Food and Agricultural Organization of the United Nations. 18 pp

Fronzek, S., & Carter, T. R. (2007). Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs. *Climatic Change, 81*(S1), 357–371.

Guo, J., Chen, H., Xu, C. Y., Guo, S., & Guo, J. (2012). Prediction of variability of precipitation in the Yangtze River Basin under the climate change conditions based on automated statistical downscaling. *Stochastic Environmental Research and Risk Assessment, 26*(2), 157–176.

IPCC. 2007. *Contribution of Working Groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change* (pp. 104). Core Writing Team, R. K. Pachauri and A. Reisinger (Eds.) Geneva: IPCC.

Maraun, D., Wetterhall, F., Ireson, A. M., Chandler, R. E., Kendon, E. J., Widmann, M., Brienen, S., et al. (2010). Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. *Reviews of Geophysics, 48*, RG3003. doi:10.1029/2009RG000314.

Messami, M., Gachon, P., Ouarda, T. B. M. J., & Saint Hilaire, A. (2008). Automated regression-based statistical downscaling tool. *Environmental Modeling and Software, 23*(6), 813–834.

Paeth, H., Hall, N. M. J., Gaertner, M. A., Alonso, M. D., Moumouni, S., Polcher, J., Ruti, P. M., Fink, A. H., Gosset, M., Lebel, T., Gaye, A. T., Rowell, D. P., Moufouma-Okia, W., Jacob, D., Rockel, B., Giorgi, F., & Rummukainen, M. (2011). Progress in regional downscaling of west African precipitation. *Atmospheric Science Letters, 12*, 75–82. doi:10.1002/asl.306.

Parry, M., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change, 14*(1), 53–67.

Poluektov, R. A., & Topaj, A. G. (2001). Crop modeling: Nostalgia about present or reminiscence about future. *Agronomy Journal, 96*, 653–659.

Reid, S., Smit, B., Caldwell, W., & Belliveau, S. (2006). Vulnerability and adaptation to climate risks in Ontario agriculture. *Mitigation and Adaptation Strategies for Global Change, 12*(4), 609–637.

Rosenzweig, C., Parry, M. L., Fischer, G., Frohberg, K. (1993). *Climate change and world food supply*. *Research report* (Vol. 3, pp. 54–60). University of Oxford, United Kingdom, Environmental Change Unit.

Salford-Systems. (2001). *Classification and regression trees a robust decision-tree technology for data mining, predictive modeling and data processing* (p. 335). San Diego: U.S.A.

Tacoli, C. (2011, April 20). Not only climate change: Mobility, vulnerability and socia-economic transformations in environmentally fragile areas of Bilivia, Senegal and Tanzania. *Human Settlements Working Paper*, *28*(February).

Themeßl, M., Gobiet, A., & Leuprecht, A. (2011). Empirical-statistical downscaling and error correction of daily precipitation from regional climate models. *International Journal of Climatology, 31*, 1531–1544. doi:10.1002/joc.2168.

Thornley, J. H. M., & Johnson, I. R. (2000). *Plant and crop modeling: A mathematical approach to plant and crop physiology* (p. 661). Caldwell, New Jersey: The Blackburn Press.

Treut, L., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., & Tignor, M. (2007). Historical overview of climate change science. *Earth, 1*, 93–127.

Wood, R. (2008). Climate change: Natural ups and downs. *Nature* (Vol. 32, pp. 2283–2300).

World Bank, W. B. (2009). *World development report 2010: Climate change*. *World development* (Vol. 2009, pp. 1–45). New York: World Bank Publications.

Zeng, N. (2003). Drought in the Sahel. *Science, 302*, 999–1000.

Mamadou Adama Sarr received his PhD from the Université Jean Moulin Lyon III, France. His current affiliation is as a Researcher with the Centre de Suivi Écologique, Dakar, Senegal. He was also a teacher and a post-doctoral Fellow in the Laboratory of Sustainable Development and Territorial Dynamics, Geography at the Université de Montréal. His research interests are in climatology, climate Change, regional climate modeling, climate variability and extreme, Geographic Information Systems and Socio-Ecological Systems.

Ousmane Seidou obtained his undergraduate degree in civil engineering in 1996 at the École Mohammadia d'ingénieurs, Rabat, Morocco. After a short stay in a construction company, he completed a postgraduate diploma in applied informatics at the École Inter-États des Ingénieurs de l'Équipement Rural in Ouagadougou, Burkina Faso. He completed his master degree and his PhD at the École polytechnique de Montreal in 2002, before Joining the Institut National de la Recherche scientique, Centre Eau, Terre et Environnement in Quebec from 2003 to 2007. He then joined the university of Ottawa, where he teaches various courses related to water resources engineering. He is involved in several national and international research projects related to climate and water interaction, hydrological modeling, adaptation to climate change and food security.

Christopher R. Bryant received his doctorate in 1970 at the London School of Economics and Political Science (LSE), London. He was progressively Assistant, Associate and Full Professor in Geography at the University of Waterloo (1970 to 1990), then Full Professor in Geography the University of Montréal (1990 to 2014), and is now Adjunct Professor in Geography at the University of Montréal and also in the School of Environmental Design and Rural Planning, University of Guelph. He is one of the international leaders in research on urban/periurban agricultures (Canada, Western Europe and elsewhere), and he is also a recognized leader in the domain of adaptation of human activities (and especially agriculture) to climate change and variability, in local and community development, and in the strategic planning for local and regional development for and by citizens.

Angelina Amadou received her Ph.D degree from Howard University in Washington, DC, and her master's degree from the University Abdou Moumouni of Niamey in Niger. She is also holds a bachelor degree in Applied Computing from the University of Windsor, Ontario, Canada. Dr. Amadou holds a position of lecturer within the Department of Physics and Astronomy at Howard University. Her research focuses on the foremost issues of climate change and variability. She has also developed an interest in data retrieval algorithms in the areas of atmospherics radiation in order to improve current atmospheric models.

Chapter 11
Facing Climate Change Through Sustainable Agriculture: Can Results from China Be Transferred to Africa?

Liette Vasseur and Minsheng You

Abstract With increased demand for healthier and safer produce, China and many other countries have looked at the use of more environmentally friendly agricultural techniques. These techniques have included more sustainable practices such as intercropping systems, cover crops, water retention basins, which may help maintain production of some important staple or commercial crops (e.g. rice, tobacco and tea), while reducing the use of chemicals (pesticides or fertilizers), erosion and water usage. These strategies have been very beneficial in reducing risks but could they have many more advantages in the face of climate change? Despite the distances, both China and Africa are facing impacts from climate change. In China, predicted increased temperatures and changes in precipitation patterns may lead to reduced crop yields and in some cases, changes in quality of produce. In Africa, precipitation is predicted to be the main concern with rainfall being more unpredictable and less common. In both cases, agricultural systems have started to adapt to these changes but at drastically different paces. In this chapter, we focus on some preliminary results and lessons learned that can be extracted from the introduction of these sustainable techniques in China as a means not only to help reduce chemicals and restore soil properties but also as better ways to adapt to climate change. The discussion leads us to examine what are the main ingredients that need to be included to ensure that such practices help adapt to new changing conditions and the lack of information that may limit their adoption. Finally, we propose possible paths to move forward in helping farmers in rural communities of Africa and China access knowledge and gradually adopt more adaptive practices to face climate and environmental changes.

Keywords Intercropping • Diversification • Agricultural policies • Food security

---

L. Vasseur (✉)
Department of Biological Sciences, Brock University, St. Catharines, ON, Canada
e-mail: lvasseur@brocku.ca

M. You
Faculty of Plant Protection, Fujian Agriculture and Forestry University, Fuzhou, China
e-mail: msyou@iae.fjau.edu.cn

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_11

11.1 Introduction

Food security remains one of the most preoccupying issues for sustainable development. With an ever increasing world population, the agricultural system will have to maintain and in fact increase production in order to feed the predicted nine billion people by 2050 (Goulding and Whitmore 2012). There are however other concerns about the sustainability of the current industrial agricultural system including its extreme reliance on chemical fertilizers and pesticides (i.e. mainly fossil fuels) (Horrigan et al. 2002). This reliance has led to issues of soil erosion, water runoff, development of insecticide resistance in pests, and increased levels of chemical residues in produce, soil and water. Impacts are observed in the decline of biodiversity and ecosystem services (Horrigan et al. 2002).

Climate change adds other risks that may affect productivity such as extreme events (including floods, droughts and heat waves), increased temperatures, and changes in rainfall patterns (frequency, seasonality, and amount). With increased temperatures, several pests and diseases have already been able to expand their range and this is predicted to continue increasing. Under such scenarios, agriculture is increasingly vulnerable which may lead to greater challenges, especially for developing countries, mainly in Africa. Already, Smith et al. (2007) estimated that in 12 countries of Africa, the average food insecurity rate was at 59 %. The most vulnerable regions are located in Sub-Saharan Africa where most people do not consume enough food and live in rural regions.

It may be possible for agriculture in industrial countries to adapt to climate change through advanced technologies. In developing countries where resources and research are limited, adaptation solutions may be restrained leading to greater vulnerability.

Reducing vulnerability and enhancing resilience and sustainability of the agricultural system in many countries like Africa means exploring alternative (or sometimes forgotten) ways to improve productivity. To do so, interdisciplinary research is required and examples from various countries can be useful. New alternatives for safer and productive farming are frequently referred to as sustainable agriculture. It represents any production technique or practice that is more environmentally friendly. Through sustainable agriculture, it is suggested that biological and genetic diversity can be restored making it more acceptable for communities and economically sustainable (FAO 2011).

Alternative agricultural techniques include restoration of degraded lands, agroforestry, genetically-modified resistant organisms and intercropping. In sustainable agriculture, practices tend to move away from industrial energy demanding systems and to reduce impacts on land and water (Upreti and Upreti 2002; Schmidt et al. 2005; Schmitzberger et al. 2005; Peterson et al. 2006; Manhoudt et al. 2007). Some of these systems reduce the reliance on the use of chemical fertilizers and pesticides that are damaging to native species of plants and animals, and to human health. Because sustainable agriculture promotes diversification, it helps enhance the capacity of farmers to be resilient against climate change and the reliance on fossil fuel inputs. At the same time, it helps maintain biodiversity within agricultural areas (Peterson et al. 2006; Manhoudt et al. 2007; Kohler et al. 2008).

Unfortunately, several technologies are quite expensive and require intensive research to optimize yields, limiting their use and adoption in developing countries. Some techniques can be more accessible such as intercropping and agroforestry. Although they are often considered low tech practices, such strategies may be the sustainable alternatives of the future for several countries. For rural communities of Africa, reliance on modern biotechnology and foreign chemical inputs cannot be sustainable, especially in the face of climate change.

In this chapter, we summarize some of the alternative agricultural management techniques that are being researched and promoted in China and, from these results, examine their possible applications in Africa. Here, we examine mainly the role of polyculture, intercropping and cover crops as potential ways to improve productivity and reduce reliance on pesticides and water, especially in relation to a changing climate. These techniques can also help improve soil structure and increase biodiversity and resilience against climate change impacts. We use the examples from China as this country has in recent years increased its research in sustainable agriculture. We then discuss the role of these techniques as major ways to adapt to climate change and also mitigate greenhouse gas emissions.

11.2 The Changes in Agricultural Systems in China

China is now considered the second most important economic power after the United States. With economic growth and the rise of the mid-class society, China has had to satisfy a greater demand for food including not only vegetables and fruits but also meat. Since the 1990s, meat consumption has more than doubled (FAO 2011). This change in food habits has led to intensifying agricultural activities, especially during the 1990s. Crops grown in China are diverse and include fruits and vegetables. Two main staple crops dominate the landscape depending on the region: the southern part of the country grows mainly rice while the northern agricultural system supports wheat farming (Fig. 11.1). In addition, the country produces several cruciferous crops such as cabbage and broccoli, tomatoes and eggplants. Current production in terms of rice amounts to 201.0×10^6 tons, wheat 117.4×10^6 tons, and vegetables to 679.3×10^6 tons. In addition, the diversity and amount of fruits being produced is linked to its wide range of climatic conditions from tropical to temperate. Tea plantations are also a large component of the agricultural landscape of the southern regions of China. Indeed, China produces 162.3×10^4 tons of tea and the varieties are as diverse as the locations where they are grown. Finally, canola and other plants are also used to produce oil and other consumption products. In fact, China has become the third largest producer of canola in the world with 13.4×10^6 tons. Without such large volumes of production, the country would have difficulty feeding its own population and would have to rely heavily on international market to survive. This amazing advancement of the

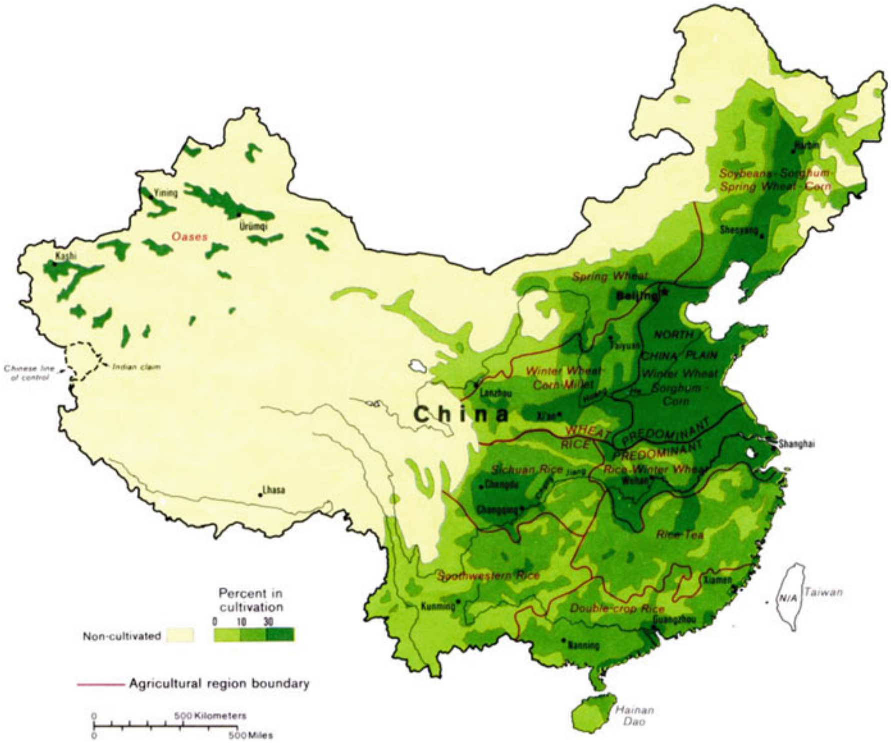


Fig. 11.1 Map of China showing the two major areas of cultivation: rice (Southern Region) and wheat (Northern Region) (Source: Map No. 800635 (544061) 5-86 – produced by the U.S. Central Intelligence Agency on Wikimedia Commons)

agricultural industry has come with some prices and new challenges. The above figures come from the "Annual Agriculture of China" at the website: http://www.stats.gov.cn/tjsj/ndsj/2012/indexch.htm.

Over 300 million farmers provide a large part of the produce and grains to be able to largely feed the Chinese population. China has however some limitations. First, it has only 10 % of the arable land of the world but 22 % of the world's population. Intensification of the agroindustry has led to some serious issues for the country (FAO 2011). Notwithstanding health problems such as diabetes, obesity and cancers that are on the rise, environmental conditions have deteriorated with concerns for instance, over water quality and quantity, significant decline in biodiversity, loss of soil due to erosion and runoff. There is a great need to optimize production in a sustainable manner in order to reduce environmental and health impacts.

Historical issues were pest management, soil fertility and urban development. Now, climate change and especially uncertainty in precipitation and temperature patterns (including extreme events) are increasingly important. In China, 75 % of arable lands are under cultivation; 30 % of the land is desert ecosystem (mainly in the north) but threatened to increase due to a decline in precipitation and higher temperatures leading to greater evaporation. Issues of pesticide residues, soil erosion and fertility, desertification due to climate change, and extreme events remain concerns that the country must deal with more seriously in the near future.

With increasing pressures to reduce pesticide use, especially in recent years in China, researchers have turned towards more ecologically-based techniques such as parasitoid/predator release, intercropping and push-pull strategy (Shi et al. 2011). In fact, China has leapt forwards in the numbers of organically cultivated lands since 2005 and is now second after Australia in moving forward (Shi et al. 2011). Among these techniques, the promotion of increased plant diversification through intercropping seems promising. Indeed, plant diversification can lead to improved arthropod diversity, mainly natural enemies of pests, enhancing ecosystem stability (Altieri 1994; You and Xu 2000; You et al. 2004; Lai et al. 2011a). A majority of agroecological studies show that structural architecture (i.e. spatial and temporal crop arrangement) and management (e.g. crop diversity and input levels) attributes of agro-ecosystems influence herbivore dynamics. Most experiments that have involved mixing accessory plant species with the primary host of a specialized herbivore resulted in lower population densities of the specialized herbivores (Altieri et al. 1984; Andow 1991; Cai et al. 2007; Cai and You 2007; Lai et al. 2011a; Lin et al. 2011).

Diversification can also improve crop system functions through partitioning of resources (Theunissen 1997; Lin 2011). Research into the areas of polyculture, agroforestry, intercropping and sustainable agriculture alternatives has intensified over the last decade as these techniques have the capability of maintaining soil fertility through nutrient and water management while simultaneously increasing productivity, in addition to reducing pest incidence (Andersen et al. 2004; Lithourgidis et al. 2011; Tuomisto et al. 2012). It has been suggested that the right combination of plants can even lead to facilitative effects, thus improving the production of crops. These types of results were observed in a greenhouse experiment with bean-onion intercroping (Dehaan and Vasseur 2014).

11.3 A Few Promising Examples from China

In this section, we describe some of the projects and results from the research group at the Institute of Applied Ecology of the Fujian Agriculture and Forestry University, Fuzhou, China, in sustainable agriculture and for some cases, their implications for better production and economic benefits. While we acknowledge that other studies are being conducted in many places in the world, we aim to describe some cases that we believe to be of interest for African countries dealing with limited or declining production in the face of climate change. There are other excellent publications that are worth referring too and have been an inspiration in this chapter such as the books *Biodiversity and Insect Pests-Key Issues for Sustainable Management* (Gurr et al. 2012 (Wiley-Blackwell)) and Habitat management in biological control (Zhao et al. 2013, *Chinese Journal of Applied Entomology*, Vol. 50: 879–889), and manuscripts (e.g. refer to several recent review articles in *Agronomy for Sustainable Development*).

11.3.1 Intercrops and Polycultures as Insurance Agents

The first case described here is the potential of intercropping garlic and tobacco to help reduce pests and improve economic returns (Lai et al. 2011a, b). Several species of insect pests, especially aphids, are well known to colonize tobacco fields thus causing damage and loss of revenue for farmers. Among them, green peach aphids *Myzus persicae* (sulzer), whitefly *Bemisia tabaci* and rice green stink bug *Nezara viridula* Linnaeus are the primary pest species found on tobacco plants (Ma and Li 2003; Ma et al. 2007a). These pests can reach high densities on young plants, causing water stress and wilting, leading to plant damage. They can also encourage dark mildew, affecting leaf photosynthesis further reducing yield (Wu et al. 2003). Piercing-sucking pests have also been considered a vector for virus transmission, including the cucumber mosaic virus (CMV), potato virus Y (PVY), tobacco etch virus (TEV) and tobacco leaf curl virus (TLCV) (Zhu et al. 2002; Ma and Li. 2003; Ma 2006; Ma et al.. 2007a, b; Lai et al. 2011a). For example, green peach aphids were responsible for transmitting 25–30 % of all the types of mosaic viruses affecting 40 % of flue-cured tobacco plants in an area of Chongqing, China in 2005 (Qing et al. 2005). Economic damage by whiteflies on tobacco was as high as 5 hundred million dollars in the US in 1991 (Perring et al. 1993; Wu et al. 2002).

Field trials were conducted in 2008 and 2009 in Longyan, Fujian province, China, to evaluate the role of garlic, *Allium sativum*, as a deterrent crop to help control the primary piercing-sucking pests, *Myzus persicae*, *Bemisia tabaci* and *Nezara viridula*, as an intercrop in flue-cured tobacco fields (Lai et al. 2011a). The effects of garlic intercropping on piercing-sucking pests in tobacco fields were primarily analyzed from the perspective of community ecology in three intercropping arrangements and a tobacco monoculture. The results showed that the abundance of piercing-sucking pests significantly decreased in intercropping systems with garlic in flue-cured tobacco fields. During this 2-year study, it was possible to show that in intercrops, aphid abundance could be almost eliminated even when there were peaks in their populations (34.7–39.0 % in 2008 and 42.0–47.2 % in 2009) (Lai et al. 2011b). What is more important for farmers is that the tobacco mosaic virus occurrences significantly decreased by an average of 30 % in intercrops versus monocultures. With less damage, the economic benefits of flue-cured tobacco intercrops with garlic showed an increase from 52.1 to 80.2 % depending on the type of intercropping system.

One of the main reasons for the success of such intercrop systems is the use of garlic. Indeed, *Allium* species in general are commonly grown vegetables in all countries of the world and most may have insecticidal or repellent properties (Bakri and Douglas 2005; Lai et al. 2009). It is therefore a great way to control insect pests and diseases in vegetable fields while reducing the use of pesticides. Dehaan and Vasseur (2014) have also suggested that onion can also play a facilitative role in intercrop also leading to greater yields. The fact that this genus is common around the world can lead to its adoption in various countries. The other interesting element of such intercrops is the possibility to also reduce weeds while slightly covering and anchoring the soil against erosion during droughts. Further studies are currently needed to better understand the roles of such intercrops during extreme events such as drought and heavy rainfall expected under the scenario of climate change.

Polycultures can also contribute to improve sustainability of the agricultural system. Rice (*Oryza sativa* L.) is a basic food staple widely cultivated throughout the world including in Asia and Africa (FAO 2004). Most cultivation is undertaken in a monoculture system where insecticides must be used to manage pests. However, overuse and/or misuse of pesticides have been credited with having detrimental effects on natural enemies (Schoenly et al. 1996), increasing pest resurgences (Chellial and Heinrichs 1980) and pest resistance to insecticides (Nagata 2002; Chen 2009a). Yao et al. (2012) have demonstrated that it is possible to use polycultures as an alternative cropping system to first reduce pest damage on rice and at the same time, increase the diversity of crops. While Yao et al. (2012) mentioned that yields may not differ between monocrops and polycrops in this study, infestation by plant-hoppers was reduced leading to better crop quality. Indeed, like intercropping, polyculture allows for an increase in crop diversity and possible insurance that at least one species will be harvested at the end of the growing season (Lithourgidis et al. 2011; Tuomisto et al. 2012). Diverse communities are usually less susceptible to stress than communities with one or a few species (Steudel et al. 2012).

11.3.2 Cover Crops as a Stabilizing Factor

Tea (*Camellia sinensis*) is a perennial evergreen shrub cultivated for the production of a beverage composed of tender young shoots. At present, tea plants are being cultivated as one of the main cash crops in many parts of the southern provinces of China. But plantations are facing many environmental challenges such as severe damages caused by insect pests and diseases (Sudoi et al. 1996; Wang et al. 2004), contamination by chemical residues resulting from overuse and/or misuse of pesticides (Kumar et al. 2004; Tewary et al. 2005), soil erosion as most plantations are located in mountainous regions and finally, climate change, especially due to extreme events of rainfall or drought. This situation has led to a reduction in marketability of this important export commodity (Kleter et al. 2009). Pesticides use has been pursued under the guidelines of the maximum residue limits (MRLs) and regulated under the tolerance limits of the Commission of European Communities, the Environmental Protection Agency, the Food and Agricultural

Organization, Food Control, and Codex Alimentarius Commission. In recent years, there has been an increased interest to develop better ecologically-based and sustainable management practices that can reduce these threats on this important cash crop. This is especially important in these two provinces where many rural communities rely on this crop as a life-supporting source for principal income and economic growth. Export restrictions play major roles in sustainability of these enterprises and communities.

Tea plantations are intensively managed monocultures (Chen and Chen 1989) where yield can be reduced from 5–55 % [5, 8] to 100 % in some cases (Muraleedharan and Chen 1997) if no pesticide is applied. Storkey and Cussans (2007) have argued that to maintain a sustainable agroecosystem, there is a need to strike a balance between species diversity and productivity in such a system. Cover crops in annual or perennial crops can therefore help reduce weeds and improve diversification with the potential benefits of reducing pests while increasing pest predators (Chen 2002; Peng 2006; Song et al. 2006). Cover crops have also been credited for retaining the soil matrix during heavy rainfall thus reducing the issues of runoff and soil erosion while in periods of lower rainfall, helping reduce evaporation (Peng 2006; Song et al. 2006; Peng et al. 2007). Chen et al. (2011; Chen 2011) have shown that cover crops can help reduce issues of pest damage by providing some cover for pest predators. While in the short term these effects may not be completely clear, Vasseur et al. (in preparation) suggest that cover crops modify the tea plantations leading to more balanced and diverse agroecosystems. Since some ecosystem services and functions can therefore be re-established, it is expected that under environmental or climatic disturbances, the system will be more resilient.

Other features have also been examined in tea plantations and other crops to help reduce the risk of extreme events, mainly heavy rainfall and most importantly droughts. In tea plantations, for example, water basins systems have also been deigned to retain water during the rainy season and for use when prolonged dry periods occur. Similarly in rice fields, alternative methods are being tested with some potential benefits. For example, the System of Rice Intensification (SRI) has been suggested as a way to improve or maintain rice cultivation by managing the plants, soil, water and nutrients instead of increasing the use of water and chemical fertilizers and pesticides (Uphoff 2006, 2007). In most cases, however there is a need to first define these alternative strategies and then evaluate their effectiveness and sustainability as a function of the local conditions and considering the future scenarios of climate change for a given region. For example, in the case of SRI, Nguyen (2007) reported that there was no yield advantage when this was tested in Vietnam and since it is labour intensive, it may not be acceptable for many farmers.

While ecological techniques may be very effective in reducing weeds and pests, in some cases, even they cannot completely control all the conditions and other alternatives need to be used. In plant production, soil nutrients, water and sunlight are considered liming factors and plants will deal with immediate conditions both above and below ground (Tilman 1988; Thorsted et al. 2006; Qasem 2006; Mariotti et al. 2009). Under climate change scenarios, increasing temperatures and changes in precipitation patterns may lead to production being negatively affected if farmers do not adapt to such changes. The current monocrop systems and the intensive use of chemical fertilizers and pesticides are considered more or less sustainable in the long term. China with its growing population and the susceptibility of its agricultural sector to threats from industrial techniques is now pushing to move towards a more sustainable system. Several of these techniques are also considered as important to deal with climate changes. In the next section, we explore how these techniques can be either transferred to developing countries of Africa or in some cases, be reappropriated by them as some were used in the past and have since been long forgotten due to industrialization pressures.

11.4 From China to West Africa: Designing a Way Forward

Several projects and major efforts have been initiated and supported by international governments and agencies in West Africa to improve food security through improving agricultural techniques and production. Over the past four decades, efforts have been concentrated in transferring technologies and seeds from northern industrial countries with the idea that they can readily be used and are effective on a large scale. However recent observations and numbers suggest that this is not the case (FAO 2011) and with a changing climate, productions are no longer able to increase and meet the demands of the local populations. Agricultural land expansion in West Africa has helped reduce the pressures but low yields even with improved techniques remain a problem (Challinor et al. 2007). As Lahmar et al. (2012) report, such low yields have "prompted African governments to undersign the Abuja declaration of 2006, placing the green revolution of agriculture in their political agendas and setting the goal of widespread fertilizer use in sub-Saharan Africa (www.nepad.org)." However, can this be sustainable and achievable? Current literature, reports and personal observations (Vasseur) suggest that industrially intensive agriculture with increased use of fertilizers will not bring productivity at levels that will reduce malnutrition and food insecurity. There are many reasons for this, one of them being climate change:

11.4.1 Current Situation: Politics, Production Versus Environmental Issues

Africa in general, but especially Western Africa, continues to suffer from food insecurity, and low agricultural productivity with an increasing population (FAO 2012). A third of Africa's population is located in West Africa where growth remains among the highest at 2.6 %. With a high fertility rate (4.6 children per woman) and a very young population (about 40 % being less than 15 years old in 2010), the agriculture sector must maintain its growth to limit the number of malnourished people (FAO 2012). In sub-Saharan Africa, over 55 % of the population is involved in agriculture and most of the land is owned by men although women share more than 55 % of the work on the farm (FAO 2012).

The main limitation for agricultural productivity in Western Africa is related to soils, which are old and weathered with coarse texture (Lahmar et al. 2012). These soils are known to have limited water holding capacity, and low nutrients and soil organic matter (Bationo et al. 2007). Studies have shown that in such soils, with no additional soil organic matter and gradually nutrients, organic matter is rapidly depleted leading to significant decline in crop productivity (Bationo et al. 2007). The main reason for this vulnerability is linked to the soil composition which is mainly composed of sand with little clay. Indeed, Eswaran et al. (1997) report that less than 10 % of this region has high agricultural soil potential. It is important to remember that over 55 % consists of desert and very low productive lands and this area is increasing because of climate change and other phenomena leading to desertification (Eswaran et al. 1997). Unless fertilizers, which most poor farmers cannot have access to, are used on a regular basis, crop productivity continues to remain limited. The use of chemical fertilizers has not yet resolved the problem of limited water holding capacity which can usually be maintained with soil organic matter.

Researchers and international organizations have suggested several techniques and solutions in order to increase productivity. It is clear that farmers need to adopt new solutions, especially to increase soil organic matter and gradually nutrients with better water holding capacity. To do so, the range of solutions has included new genetically modified crops, intensive irrigation systems (often in areas where water is a limiting factor for daily consumption), use of chemical fertilizers, conservation agriculture, and other more environmentally friendly practices such as drip irrigation. Currently several of these proposed solutions have not been implemented or if they have been, they have had little success due to limited financial resources or lack of expertise. In fact, even after more than 30 years, the situation remains relatively unchanged with only slight improvement in food access (FAO 2012). Even solutions that may be considered more sustainable than industrial agriculture based on fossil fuels have received little attention. Lahmar et al. (2012) argue that conservation agriculture, as a technique to improve soil organic matter, "is unlikely to be adopted by farmers in systems where crop residues may have higher value uses than mulching" (p. 159). They have suggested that addition of beneficial shrubs, such as *Piliostigma reticulatum*, may be a way to improve conditions of soil fertility and water supply. They also alluded to the use of intercropping of these species. Can some of the lessons learned from China complement some of these proposed solutions?

We argue that while no one technique of agriculture is perfect in itself, there are several that can be used to enhance sustainability. Among them, as we have seen in the previous section, are intercropping, polyculture and cover crops all of which are certainly promising. The main reason is that they reduce the concerns related to monocultures as they increase diversification; issues related to soil erosion and chemical pesticides and fertilizers by improving habitats for pest predators and improving soil organic matter and potentially fertility with the use of legume intercrops; and water shortage through reducing evaporation using cover crops. Other additional techniques can also be integrated into a sustainable agriculture strategy including integrated pest management and nutrient management with addition of compost or other sources of nutrients. Interestingly enough, several of these solutions are in fact far from new. They were traditionally used in those countries but with mechanization and industrialization of the agricultural sector, they have been forgotten. The question therefore is why are they not adopted and widely employed in Western Africa?

The failure or the limitation to introduce sustainable agriculture in Western Africa relates to several causes, some of them being interconnected. At the national level, many countries are susceptible to the influence of larger markets and multinational companies that continually push for more intensive agriculture, increasingly relying on synthetic chemical fertilizers and pesticides and heavy equipment. While farmers may not be able to afford any of these, loans and incentives are made to attract them. Observations and data from a study in Burkina Faso (Vasseur, unpublished data) show that social pressures are strong for men to acquire these items and produce commercially promoted products such as cotton, even though those same farmers remain in poverty and are unable to pay their expenses year after year. The governments may also be to blame as agricultural extensionists tend to maintain the status quo by encouraging greater production through the use of larger quantities of fertilizers and pesticides. Without a mind change at the governmental level, changes in communities are difficult.

This immobilization of the system is generally exacerbated by the lack or limited education of the farmers in rural areas. With few knowing how to read and write or having any agronomic background, chemicals are frequently misused or overused. This leads to increased erosion, water contamination, greater pest resistance and unfortunately many other human health issues (Vasseur, data unpublished). Lack of education brings other issues such as the incapacity of farmers to question extension workers and practices that may be harmful for them and their families. With men increasingly having to go in urban centers to work, women are becoming the main person caring for the farm. She is often more vulnerable to influences from outside and as most women are even less educated than men in many developing countries, their capacity to evaluate best practices remains limited. Encouraging women to go to school and gradually having a stronger network for agricultural practices can certainly void this knowledge gap. To get there, national policies and some of the rural traditions may have to be changed.

Pingali et al. (2005) have also suggested that networks and rebuilding traditional support may help improve resilience of rural communities and their agricultural system. For many years, with industrialization of the agricultural sector, local knowledge has been dismissed as a valid approach to sustainable agriculture. Like in China, however, such local knowledge and traditional techniques may have greater advantages and adaptive capacities against a changing climate and degrading environment than current advanced intensive agricultural techniques (Horrigan et al. 2002; Pingali et al. 2005). The introduction or reintroduction of sustainable agricultural practices may take some time to be accepted and adopted by communities. Demonstration projects and further research showing their potential can help persuade them to change their habits. Support of the extension workers may be needed as well. From the Chinese experience and other emergent countries, the use of bottom-up incentives as well as top-down policies can help transform the agricultural sector over time.

Rainfall is considered one of the most limiting factors for agricultural production in Western Africa (Brooks 2004). Current climate change projections for Western Africa indicate that water will become an ever increasingly important limiting factor for agricultural sustainability. With increasing temperatures of the order of 0.8 % by 2025 and 1.7 % by 2050 as well as a decline in annual precipitation by 3.4 % by 2025 and 7.3 % by 2050 (Nelson et al. 2010), the need to modify intensive agricultural practices will become urgent. Several of these countries have already noted that water will be the main issue for their sustainability in the future and this is due especially to its need in agriculture. As mentioned by FAO (2011), there is unfortunately an obvious lack of initiatives to better understand the balance between climate, soils, crop cultivation and food security. In rural communities of Burkina Faso, as Nielsen and Reenberg (2010) report, people are in general well aware of the declining productivity and the lack of reliance on local produce for food security. As they mention: “low yield combined with the intensive demand for labour (sowing, weeding and harvesting) has resulted in four households giving up cereal cultivation altogether” (p. 466). With the impossibility of making a living from agriculture, like in many other countries, men are therefore moving to urban centres to try to find jobs and provide for family needs. The change in agriculture is therefore even more important because cereal and rice are staple foods difficult to grow in such conditions. Organic farming may at least help with subsistence agriculture and maintain a certain level of security. As we have seen in this chapter, there are many opportunities and possibilities that can be apply to Western Africa, not only in China. As Goh (2011) argue, organic farming is not only important as an adaptive solution to climate change but also as a mitigation process. Indeed, as mentioned earlier in the introduction, intensive agriculture relies heavily on fossil fuels; therefore such a transformation can help countries reduce their reliance on such chemicals and further contribute to the global reduction of greenhouse gas emissions.

11.5 Conclusion

Is Western Africa ready? It is true that all countries, not only a few like China, need to develop adaptive management strategies to deal with climate change in the agricultural sector. China has shown that there might be interesting opportunities and this can be achieved over time through advances in research in rural communities and changes in policies. A two prone approach may be the best approach to ensure a national commitment as well as social acceptance and adoption of more sustainable agricultural techniques.

In Western Africa, several more steps will be needed to enhance agricultural sustainability and its resilience in the face of climate and environmental changes. Education will contribute significantly in the future to improving not only literacy but also creativity and innovations in these regions where new and old practices must be introduced or reintroduced to ensure a more stable and sustainable production. At the same time, governments must also realistically examine their current policies and ensure that they allow for adaptation strategies to be implemented and not only for economic growth. Learning from emergent countries can also lead to greater success with practices that may have failed in the past due to lack of social acceptability. The communalities between the countries can help make the jump in a more positive way that pressures coming from larger international organizations or industrialized countries. In the end, improving agriculture sustainability in Western Africa will have to lead to significant changes in policies, from education to market demands, and current practices.

References

Altieri, A. (1994). *Biodiversity and pest management in agroecosystems*. Binghamton: Haworth Press.

Altieri, M. A., Letourneau, D. K., & Risch, S. J. (1984). Vegetation diversity and insect pest outbreaks. *Critical Review Plant Science, 2*, 131–169.

Andersen, M. K., Hauggaard-Nielsen, H., Ambus, P., & Jensen, E. S. (2004). Biomass production, symbiotic nitrogen fixation and inorganic N use in dual and tri-component annual intercrops. *Plant and Soil, 266*, 273–287.

Andow, D. A. (1991). Vegetational diversity and arthropod population response. *Annual Review Entomology, 36*, 561–586.

Bakri, I. M., & Douglas, C. W. I. (2005). Inhibitory effect of garlic extract on oral bacteria. *Archives of Oral Biology, 50*, 645–651.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., & Kimetu, J. (2007). Soil organic carbon dynamics, functions an management in West African agro-ecosystems. *Agriculture Systems, 94*, 13–25.

Brooks, N. (2004). *Drought in the African Sahel: long term perspectives and future prospects* (Working Paper 61) Tyndall Center for Climate Change Research, UEA, Norwich. http://www.cru.uea.ac.uk/we118/publications/TynWP61.pdf

Cai, H. J., & You, M. S. (2007). Effects of garlic-Chinese cabbage intercropping systems on the guilds of arthropoda communities in vegetable fields. *Entomology Journal East China, 16*, 1–7.

Cai, H. J., Li, Z. S., & You, M. S. (2007). Impact of habitat diversification on arthropod communities: A study in the fields of Chinese cabbage, Brassica chinensis. *Insect Science, 14*, 241–249.

Challinor, A., Wheeler, T., Garforth, C., Craufurd, P., & Kassam, A. (2007). Assessing the vulnerability of food crop systems in Africa to climate change. *Climatic Change, 83*, 381–399.

Chellial, S., & Heinrichs, E. A. (1980). Factors affecting insecticide-induced resurgence of the brown planthopper, Nilaparvata lugens on rice. *Environmental Entomology, 9*, 773e777.

Chen, Y. G. (2002). *Study on diversity retaining of arthropod and sustainable controlling of insect pests in tea orchards*. Thesis type. South China Agricultural University, Guangzhou, pp. 68.

Chen, J. (2009). Rice planthopper problems and relevant causes in China. In K. L. Heong & B. Hardy (Eds.), *Planthoppers: New threats to the sustainability of intensive rice production systems in Asia* (pp. 157–177). Los Baños: International Rice Research Institute.

Chen, L. L., Lin, S., You, M. S., Chen, S. B., Vasseur, L., & Ye, S. C. (2011). Effects of cover crops on mite communities in tea plantations. *Biodiversity Science, 19*(3), 353–362.

Chen, L. L. (2011). *Effects of tea intercropped with ground cover on the composition and structure of arthropods and other related animals*. Thesis type. Fujian Agriculture and Forestry University.

Chen, Z. M., & Chen, X. F. (1989). An analysis on the world tea pest fauna. *Journal of Tea Science, 9*, 13–22.

Dehaan, J., & Vasseur, L. (2014). Above and below ground interactions in monoculture and intercropping. *American Journal of Plant Sciences, 5*, 3319–3327.

Eswaran, H., Almaraz, R., van den Berg, E., & Reich, P. (1997). An assessment of the soil resources of Africa in relation to productivity. *Geoderma, 77*, 1–18.

FAO. (2004). *Rice is life*. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/newsroom/en/focus/2004/36887/index.html

FAO. (2011). Food and Agriculture Organization of the United Nations (FAO), *FAO statistical databases*.

FAO. (2012, February). *Stability of food security in a green economy environment* (FAO GEA Working Paper 3). Rome: FAO.

Goh, K. M. (2011). Greater mitigation of climate change by organic than conventional agriculture: A review. *Biological Agriculture and Horticulture, 27*, 205–230.

Goulding, K. W. T., & Whitmore, A. P. (2012). Developing sustainable farming systems by valuing ecosystem services. *International Journal for Agricultural Sustainability, 10*, 5–7.

Gurr, G. M., Wratten, S. D., & William, W. E. (Eds.) (2012). *Biodiversity and insect pests: Key issues for sustainable management* (pp. 360). Wiley-Blackwell.

Horrigan, L., Lawrence, R. S., & Walker, P. (2002). How sustainable agriculture can address the environmental and human health harms of industrial industry. *Environmental Health Perspectives, 110*, 445–455.

Kleter, G. A., Groot, M. J., Poelman, M., Kok, E. J., & Marvin, H. J. P. (2009). Timely awareness and prevention of emerging chemical and biochemical risks in foods: proposal for a strategy based on experience with recent cases. *Food and Chemical Toxicology, 47*, 992–1008.

Kohler, F., Verhulst, J., van Klink, R., & Kleijn, D. (2008). At what spatial scale do high-quality habitats enhance the diversity of forbs and pollinators in intensively farmed landscapes? *Journal Applied Ecology, 45*, 753–762. doi:10.1111/j.1365-2664.2007.01394.x.

Kumar, V., Ravindranath, S. D., & Shanker, A. (2004). Fate of hexaconazole residues in tea and its behavior during brewing process. *Chemical Health and Safety, 11*, 21–25.

Lahmar, R., Bationo, B. A., Lamso, N. D., Guéro, Y., & Tittonell, P. (2012). Tailoring conservation agriculture technologies to West Africa semi-arid zones: Building on traditional local practices for soil restoration. *Field Crops Research, 132*, 158–167.

Lai, R. Q., Lai, C. L., Zhong, X. J., Lin, T. R., & Li, Q. S. (2009). Garlic ethanol-extract's deterrent effect on Myzus persicae (Sulzer) and anti-feeding effect on Spodoptera litura (Fabricius) for tobacco fields. *Fujian Journal Agriculture Science, 24*, 85–99.

Lai, R. Q., You, M. S., Lotz, L. A. P., & Vasseur, L. (2011a). Responses of green peach aphids and other arthropods to garlic intercropped with tobacco. *Agronomy Journal, 103*, 856–863.

Lai, R. Q., You, M. S., Jiang, L. C., Lai, B. T., Chen, S. H., Cen, W. L., & Jiang, D. B. (2011b). Evaluation of garlic intercropping for enhancing the biological control of Ralstonia solanacearum in flue-cured tobacco fields. *Biocontrol Science and Technology, 21*, 755–764.

Lin, B. B. (2011). Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience, 61*, 183–193.

Lin, S., You, M. S., Yang, G., & Chen, L. L. (2011). Can polycultural manipulation effectively control rice planthoppers in rice-based ecosystems? *Crop Protection, 30*, 279–284.

Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., & Vlachostergios, D. N. (2011). Annual intercrops: An alternative pathway for sustainable agriculture. *Australian Journal of Crop Science, 5*, 396–410.

Ma, L.N. (2006). *The research on interaction of green peach aphid and tobacco mosaic diseases*. M.S. thesis. Southwest. University, Chongqing, China.

Ma, J. S., & Li, Z. Y. (2003). *Tobacco insects*. Beijing: China Agriculture Press.

Ma, J. S., Luo, M. H., Guo, X. L., & Jiang, J. W. (2007a). *Tobacco insects in China*. Beijing: Science Press.

Ma, L. N., Liu, Y. H., Zhang, L., Zhou, L. F., & Li, X. Z. (2007b). Effects of tobacco plants inoculated by different viruses on development and reproduction of Myzus persicae (Sulzer). *Acta Phytophylacica Sinica, 34*, 10–14.

Manhoudt, A. G. E., Visser, A. J., & de Snoo, G. R. (2007). Management regimes and farming practises enhancing plant species richness on ditch banks. *Agriculture Ecosystems Environment, 119*, 353–358. doi:10.1016/j.agee.2006.08.004.

Mariotti, M., Masoni, A., Ercoli, L., & Arduini, I. (2009). Above and below ground competition between barley, wheat, lupin and vetch in a cereal and legume intercropping system. *Grass and Forage Science, 64*, 401–412.

Muraleedharan, N., & Chen, Z. M. (1997). Pests and diseases of tea and their management. *Journal of Plantation Crops, 25*, 15–43.

Nagata, T. (2002). Monitoring on insecticide resistance of the brown planthopper and the white backed planthopper in Asia. *Jounal Asia-Pacific Entomology, 5*, 103–111.

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., Zhu, T., Sulser, Ringler, T. B. C., Msangi, S., & You, L. (2010). *Food security, farming and climate change to 2050*. Washington, DC: International Food Policy Research Institute. 140 pp.

Nguyen, N. V. (2007). *Sustainable intensification of rice production for food security in the near future. A summary report*. Rome: Secretary, International Rice Commission, FAO. 14 pp.

Nielsen, J. Ø., & Reenberg, A. (2010). Temporality and the problem with singling out climate as a current driver of change in a small West African village. *Journal of Arid Environments, 74*, 464–474.

Peng, W. X. (2006). Study on eco-physiological effects of straw mulching and intercropping white clover in tea plantation in subtropical hilly red soil regions. Thesis type. Hunan Agricultural University.

Peng, W. X., Song, T. Q., Xiao, R. L., Yang, Z. J., & Li, S. H. (2007). Effect of straw mulching on soil, tea quality and yield of young tea plantations in hilly subtropical regions. *Chinese Journal of Eco-Agriculture, 15*, 60–63.

Perring, T. M., Cooper, A. D., & Rodriguez, R. J. (1993). Identification of a new whitefly species by genomic and behavioral studies. *Science, 259*, 74–77.

Peterson, S., Axelsen, J. A., Tybirk, K., Aude, E., & Vestergaard, P. (2006). Effects of organic farming on field boundary vegetation in Denmark. *Agriculture Ecosystems Environment, 113*, 302–306. doi:10.1016/j.agee.2005.09.016.

Pingali, P., Alinovi, L., & Sutton, J. (2005). Food security in complex emergencies: Enhaving food system resilience. *Disasters, 29*, S5–S24.

Qasem, J. R. (2006). Response of onio (*Allium cepa* L.) plants to fertilizers, weed competition duration, and planting times in the central Jordan Valley. *Weed Biology and Management, 6*, 212–220.

Qing, L., Liu, Y. H., & Ma, L. N. (2005). Preliminary identification of tobacco virus types in Wulong county. *Journal Southwest Agriculture University (Natural Science), 27*, 319–322.

Schmidt, M. H., Roschewitz, I., Thies, C., & Tscharntke, T. (2005). Differential effects of landscape and management on diversity and density of ground-dwelling farmland spiders. *Journal Applied Ecology, 42*, 281–287. doi:10.1111/j.1365-2664.2005.01014.x.

Schmitzberger, I., Wrbka, T., Steurer, B., Aschenbrenner, G., Peterseil, J., & Zechmeister, H. G. (2005). How farming styles influence biodiversity maintenance in Austrian agricultural landscapes. *Agriculture Ecosystems Environment, 108*, 274–290. doi:10.1016/j.agee.2005.02.009.

Schoenly, K. G., Cohen, J. E., Heong, K. L., Arida, G. S., Barrion, A. T., & Litsinger, J. A. (1996). Quantifying the impact of insecticides on food web structure of rice-arthropod populations in a Philippine Farmer's irrigated field: A case study. In G. A. Polis & K. O. Wisemiller (Eds.), *Food webs: Integration of patterns and dynamics* (pp. 343–351). London: Chapman & Hall.

Shi, Y., Cheng, C., Lei, P., Wen, T., & Merrifield, C. (2011). Safe food, green food, good food: Chinese Community Supported Agriculture and the rising middle class. *International Journal of Agricultural Sustainability, 9*, 551–558.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., & Sirotenko, O. (2007). Agriculture. In B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, & L. A. Meyer (Eds.), *Climate change 2007: Mitigation* (Contribution of the Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change). Cambridge: Cambridge University Press. http://www.mnp.nl/ipcc/pages_media/FAR4docs/final_pdfs_ar4/chapter08.pdf

Song, T. Q., Wang, K. L., Peng, W. X., Wang, J. R., Lin, X. R., Ping, Z. F., & Yu, T. (2006). Ecological effects of intercropping white clover on tea plantation in a subtropical hilly region. *Acta Ecologica Sinica, 26*, 3647–3655.

Steudel, B., Hector, A., Friedl, T., Lofke, C., Lorenz, M., Wesche, M., & Kessler, M. (2012). Biodiversity effects on ecosystem functioning change along environmental stress gradients. *Ecology Letters, 15*, 1397–1405.

Storkey, J., & Cussans, J. (2007). Reconciling the conservation of in-field biodiversity with crop production using a simulation model of weed growth and competition. *Agriculture Ecosystems Environment, 122*, 173–182. doi:10.1016/j.agee.2006.12.031.

Sudoi, V., Khaemba, B. M., & Wanjala, F. M. E. (1996). Influence of soil applied nitrogen (NPKS 25: 5: 5:5) on *Brevipalpus phoenicis* Geijskes (Acari: Tenuipalpidae) mite incidence and damage symptoms on tea. *Annals of Applied Biology, 128*, 13–19.

Tewary, D. K., Kumar, V., Ravindranath, S. D., & Shanker, A. (2005). Dissipation behavior of bifenthrin residues in tea and its brew. *Food Control, 16*, 231–237.

Theunissen, J. (1997). Application of intercropping in organic agriculture. *Entomologial Research in Organic Agriculture, 15*, 251–259.

Thorsted, M. D., Weiner, J., & Olesen, J. E. (2006). Above- and below-ground competition between intercropped winter wheat *Triticum aestivum* and -white clover *Trifolium repens. Journal of Applied Ecology, 43*, 237–245.

Tilman, D. (1988). *Plant strategies and the dynamics and structure of plant communities*. Princeton: Princeton University Press.

Tuomisto, H. L., Hodge, I. D., Riordan, P., & Macdonald, D. W. (2012). Does organic farming reduce environmental impact? A meta-analysis of European research. *Journal of Environmental Management, 112*, 309–320.

Uphoff, N. (2006). *Report on visit to Vietnam, to review SRI progress* (16 pp). Cornell International Institute for Food, Agriculture and Development (CIIFAD). http://www.sri.cals.cornell.edu/countries/vietnam/vnntutr106.pdf.

Uphoff, N. (2007). *Reviewing SRI progress in Vietnam* (20 pp). Cornell International Institute for Food. Agriculture and Development (CIIFAD). http://www.sri.cals.cornell.edu/countries/vietnam/vnntutr106.pdf.

Upreti, B. R., & Upreti, Y. G. (2002). Factors leading to agro-biodiversity loss in developing 1297 countries: The case of Nepal. *Biodiversity and Conservation, 11*, 1607–1621. doi:1298 10.1023/A:1016862200156.

Wang, G. H., Liang, Y. F., Tian, Y. H., Wang, J. L., & Zhou, G. L. (2004). Effect of chemical insecticides on the diversity of arthropods in tea garden. *Journal of Tea Science, 24*, 99–104.

Wu, Q. J., Xu, B. Y., Xu, W. H., Zhang, Y. J., & Zhu, G. R. (2002). Bioassays on D-C tron to Bemisia tabaci of different developmental stages. *Plant Protection, 28*, 11–13.

Wu, J. W., Cai, W. Z., & Hou, T. Q. (2003). *Insects of tobacco and related integrated pest management in China*. Beijing: China Agricultural Science and Technology Press.

Yao, F., You, M., Vasseur, L., Yang, G., & Zheng, Y. (2012). Polycultural manipulation for better regulation of planthopper populations in irrigated rice-based ecosystems. *Crop Protection, 34*, 104–111.

You, M. S., & Xu, Q. Y. (2000). Species composition, richness and diversity of insect communities in cruciferous fields in Fuzhou's suburb. *Journal Fujian Agriculture University, 29*, 444–452.

You, M. S., Liu, Y. F., & Hou, Y. M. (2004). Agricultural biodiversity and integrated pest management. *Ecology, 24*, 117–122.

Zhu, X. C., Wang, Y. T., & Wang, Z. F. (2002). *Tobacco diseases in China*. Beijing: China Agriculture Press.

Zhao, Z. H., Ouyang, F., Meng, X. Y., Liu, J. H., He, D. H., & Ge, F. (2013). Habitat management in biological control. *Chinese Journal of Applied Entomology, 50*(4), 879–889.

Liette Vasseur has a PhD from Queens University and is a Full Professor in the Department of Biological Sciences at Brock University where she is also a member of the Women and Gender Studies program and the Environmental Sustainability Research Centre. Since 2014, she holds the UNESCO Chair on Community Sustainability: from local to global at Brock. She currently leads the thematic group on Climate Change Adaptation of the Commission for Ecosystem Management of the International Union for Conservation of Nature. Her research interests are highly interdisciplinary in the areas of community-based ecosystem management, climate change adaptation and resilience and sustainable agriculture.

Minsheng You received his PhD from South China Agricultural University and is a Full Professor in the Faculty of Plant Protection at Fujian Agriculture and Forestry University. He is interested in all aspects of ecology and pest management, but focuses on the application of ecological principles to real field situations, particularly in relation to biodiversity manipulation in support of ecologically-based pest management in agro-ecosystems. Over the past 30 years he has been exploring how a community is structured in a prescribed area or habitat, how a pest population interacts with its host plants, natural enemies and other environmental variables, how a biotic entity (individual, population, community) changes within a specific space or a period of time, and what strategies we can develop for improving pest management strategies and practices.

Chapter 12
Adaptation Strategies in the Valley of the Senegal River: A Social Approach to Dealing with Climate Change in Senegal

Gabrielle Tremblay

Abstract In Senegal, the drought of 1970 that affected sub-Saharan Africa was the turning point at which environmental changes were identified as a direct consequence of climate change. Remarkable changes occurred regarding rainfall variability, loss of biodiversity, drought and an increase in aridity. The degradation and modification of access to natural resources, consequences of ecological and politic issues, represent serious socio-environmental challenges considering that 70 % of the population relies directly on natural resources for survival.

In the rural communities of the Sahelo-Sudanian area of Bakel, a majority of the 200,000 citizens depends on animal husbandry and farming activities. Affected by climate change, these rural communities are now facing a lack of water resources in addition to environmental degradation, strongly impacted by unmanaged transhumance, deforestation and bushfire. However, Bakel communities adapt to climate change and try to be resilient in the face of environmental risk and disaster, using local knowledge to mitigate vulnerability and insecurity.

Specifically, adaptation strategies put in place range from agricultural and livelihood diversification, innovation to land restoration. These practices are sustained by a local non-governmental organization (NGO) working in local development through strengthening capacities and transferring knowledge.

Concepts of vulnerability, governance, local development, adaptation, strengthening capacities and resilience are applied to the socio-environmental context of the Bakel district.

Keywords Vulnerability • Decentralization policy • Natural resource management • Adaptation strategies for climate change • Climate resilience

> The impact of climate change will fall disproportionately on the world's poorest countries, many of them here in Africa. Poor people already live on the front lines of pollution, disaster, and the degradation of resources and land. For them, adaptation is a matter of sheer

G. Tremblay (✉)
Environmental and Gender Consultant, Montreal, Canada
e-mail: trem.gab@gmail.com

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_12

survival. (UN Secretary General Kofi Annan, 12th Conference of the Parties to the United Nations Framework Convention on Climate Change, 2006, Nairobi, Kenya.)

12.1 Introduction

In 2008, the *International Energy Agency* predicted that the consumption of natural resources would increase by 1,6 % over the next two decades. This increase in primary energy consumption, mainly concentrated in developing and emerging countries, is around 11 %, which would account for 62 % of global energy demand (World Energy Outlook 2008). But in an international context affected by the effects of climate change the achievement of this demand risks being undermined by the environmental consequences of climate change.

In Senegal, where 70 % of the population is dependent on natural resources for survival (UNDP 2010), the degradation and insecurity of access to resources pose significant challenges. The situation is affected first by the environmental consequences of climate change, but climate and social vulnerabilities are also exacerbated by human activities and irrational management of natural resources (World Bank 2010). For nearly two decades after the establishment of the decentralization policy, the non-application of standards in the management of natural resources and the consequences of the systemic and organizational shortcomings of local authorities responsible for environmental governance, generated preoccupying socio-environmental consequences.

In the Senegal River Valley, affected by climate change since the 1970s, many rural communities are now confronted with the degradation and insecurity of natural resources, water stress and reduced agricultural production. These conditions increase the degree of vulnerability of the populations of rural communities. Within the Department of Bakel, located in the extreme east of the country near the border with Mauritania and Mali, local people, however, are demonstrating an ability to adapt to environmental changes and water stress. They use their indigenous knowledge and develop adaptation strategies to reduce their vulnerabilities and security risks. Specifically, these strategies are taking shape through various processes of diversification, innovation and restoration that promote their climate resilience and improve their living conditions (World Bank 2010).

This chapter describes the socio-environmental consequences related to climate change impacts and institutional shortcomings in the management of natural resources in Senegal. It also discusses the concepts of vulnerability, adaptation and capacity building, through the presentation of coping strategies implemented by rural communities in the Department of Bakel that contribute to their climate resilience.

12.2 Ecological Disturbance: Climate Change and Human Activities

12.2.1 Climate Change

The effects of climate change have been felt for over 35 years by the people of Senegal, and especially in rural areas. In the valley of the Senegal River, where agro-ecological conditions are comparable to those of the Sahel, climate disruptions occur primarily by erratic rainfall, reduced rainfall, an intensification and increased recurrence of droughts, aridity and the loss of biodiversity (Senegal, Minister of Economy and Finance 2010).

In recent years in Senegal, the cycle and the length of seasons have experienced irregularities, particularly in terms of precipitation and rainfall. According to some climate models that combine higher temperatures and lower rainfall, national rainfall would have decreased by 35 % over the past two decades (UNDP 2010). Giving rise to cycles of drought and reduction in the number of water points, these phenomena have a significant impact on crop yields, especially when one considers that 11 % of crops are grown in an area receiving less than 500 mm of rain annually (World Bank 2010).

If current climate trends continue, the Senegalese Ministry of the Environment predicts a decrease in rainfall of 5–25 % over the next few years, which could result in reduced crop yields by up to 50 % by 2020. The ministry considers this of great concern because one of the principal market crops for Senegalese families is produced where rainfall represents a major resource. Further to this, the Department of Bakel is one of the last few places in the Senegal River Valley where rainfed and irrigated agriculture are practiced to a certain extent (Senegal, Ministry of the Environment 2006; UNDP 2010).

12.2.2 Anthropogenic Activities

Climatic disturbances in Senegal are also amplified by human activities that contribute to the depletion and scarcity of natural resources. Indeed, rural communities are heavily dependent on natural resources particularly to fulfill their domestic demand for wood and coal. This biomass represents 58 % of Senegal's primary energy resource involving an annual logging of 4 million m^3 (Diop 2009). The major problem with this exploitation primarily concerns the non-compliance with environmental standards and the lack of methods of rational land use planning for the use and exploitation of resources (see subsequent discussion). In 2006, deforestation and bush fires affected more than 80,000 ha of arable land, affecting soil fertility and decreasing crop yields (Diop 2009), and in 2010, it was estimated that 38 % of Senegal's land was no longer being cultivated (UNDP 2010).

In environmental terms, the impacts due to these human activities disturb the equilibrium of flora and fauna and contribute to biodiversity loss. The aridity of the soils, the destruction of vegetation cover and the drastic reduction of water sources amplify the phenomenon of scarcity of fauna and flora species. The phenomena of wind and water erosion, already exacerbated by climate change, are also amplified by deforestation of various areas.

Socially, communities find themselves facing the challenges posed by the changing pattern of cropping areas, the decrease in arable land, the disappearance of some of the traditional areas where certain forest products were characteristically exploited, the disappearance of some forest products that had been traditionally used, as well as the degradation and loss of species (Lead Afrique Francophone 2009a). These phenomena contribute to increased levels of socio-ecological vulnerabilities of communities, which must now attempt to balance their needs with the scarcity of certain resources (Senegal, Minister of Environment 2006).

12.3 National Decentralization Policy and Institutional Gaps in Local Governance

12.3.1 Senegal's Decentralization Policy

In the aftermath of independence, Senegal decided to establish a policy of decentralization of state institutions, established in the early 1960s and completed in 1996. The objective of the government was to reinforce the roles and responsibilities of local communities, by promoting the principle of subsidiarity, which is "based on the principles of local accountability, transparency, and co-management of community investment in their implementation as well as in their maintenance" (translation) (Diop 2009, 8–9).

In 1996, the 96-07[1] law completed the process of subsidiarity by transferring to local authorities nine new domains of competency,[2] including the environment and natural resources management (Ross Bethio 2007). In this domain, rural communities now possessed the responsibility to enforce local laws taking into account the geographical and environmental characteristics of the areas where they operate, and thus became responsible for territorial planning, land allocation, the management of natural areas and the protection of fauna and flora. They have also become responsible for the regulation of the use of natural resources, notably in terms of: timber

[1] Sénégal. *Loi portant sur le transfert de compétences aux régions, communes et communautés rurales, art. 192 de la loi n° 96-06 du 22 mars 1996.*

[2] (1) Management and use of the private domain of the State, and the public and national domain; (2) Environment and management of natural resources; (3) Health, population and social action; (4) Youth, sports and leisure; (5) Culture; (6) Education; (7) Planning; (8) Land use planning; (9) Urban Planning and habitat.

exploitation, the management of livestock trails, community forest management, the regulation of hunting areas, the management of water sources, the fight against bush fires, the creation of protected areas and the establishment of committees to deal with bush fires (Kremer and MBodj 2003).

> As such, (local communities) have competency relating to the management of natural resources whose effective implementation is crucial to contain the effects of agro-ecological changes related to climate change. (translation) (Lead Francophone Africa in 2009, 10)

12.4 Local Governance and Institutional Weaknesses of the Decentralization Policy

The ideal type of local governance refers to an operational institutional framework, consisting of counselors and elected officials whose training, experience and leadership allow them to implement policies and laws that have a mandate for. Efficiency refers to the knowledge and control by elected officials of the laws, texts and their roles. “It can therefore be said that the implementation of environmental initiatives in general, and their ability to fight against climate risks in particular, is directly dependent on the availability and robustness of appropriate institutions at the local level” (World Bank 2010: 38–39).

Today, nearly two decades after the establishment of this policy, the rational management of natural resources is severely put in doubt and the problem occurs both on the institutional and social levels (Lavigne Delville 2002). Indeed, resource degradation is partly the result of deficiencies in the local institutional framework, which is responsible for enforcing the standards and ensuring rational and equitable land and water planning (Kremer and MBodj 2003). However, human rights, standards, tools and institutional resources remain largely theoretical and regulations are very inadequately implemented. “The laws do exist, but the principles for their application pose problems in the absence of decrees defining the specific responsibilities at each level of the local authority” (World Bank 2010: 36).

Several factors must be taken into account to understand the circumstances of the non-application of standards and inadequate utilization of planning tools by local communities in the management of natural resources.

12.4.1 Financial Gaps and Inadequate Transfer of Skills

Institutional weaknesses in the management of natural resources emerge primarily from the lack of funding from the state in this sector. In fact, only three areas of decentralization receive new funds: health, education and youth.

Thus, the transfer of skills in this sector has not been accompanied by adequate funding and the appropriate training of administrative staff. The inadequacies in terms of competency in terms of the implementation of agreements has been rendered difficult by the limited knowledge of local leaders, limited schooling in relation to their competencies and their roles and responsibilities in the field of natural resource management. Some of the difficulties in terms of competency on the part of the local executive body is also explained by the fact that local elected officials are in office for a term of 5 years and that the new staff does not always receive the necessary transfer of appropriate skills and knowledge. This situation puts elected officials in an almost continuous search to acquire the necessary skills and increase their capacities (World Bank 2010; Senegal, Minister of Environment 2008).

On the other hand, it is important to note that the Senegal government has been aware of these difficulties and has established support and counseling programs in order to support local government actors to help them perform their roles and responsibilities (World Bank 2010).

12.4.1.1 Lack of Access to Information and Informational Vacuum

Financial gaps and the lack of training of administrative staff also affect the practices of good governance because they restrict the organization of activities for consultation and advocacy within the community, critical components of good governance processes. Awareness and information on the roles of leaders and on sustainable practices in the use of natural resources are fundamental aspects to counter illegal acts. Lack of funding limits field monitoring and the majority of the population, especially the women who are responsible for domestic water supply, wood and food, know little about the competencies transferred to the rural community, or the rights, regulations, or local codes and conventions, and nor even the use rights they hold on natural resources. This information vacuum and lack of clarity concerning user rights demonstrate that there is a significant gap in the institutional dynamics of local communities (Senegal, Minister of Environment 2008; Lead Francophone Africa 2008).

12.4.1.2 Modern Law Versus Customary Law

The coexistence of traditional or customary and modern laws is another element that must be considered in order to understand the problem of non-implementation of standards in this domain of activity, both by politicians and by civil society.

Traditionally, laws related to natural resource management were governed by customary norms that defined access to natural resources procedures. When in 1964 the government passed law 64-46 (Senegal 1996) at the national level, this modern law was decreed as the supreme law, which no longer legally recognized customary rights. Since then, though modern laws are vested with legal powers, these standards greatly lack legitimacy among the citizenry because they represent a total dichotomy with customary local practices (World Bank 2010; Lavigne Delville 1999).

> This demonstrates a lack of ownership by the people of the laws and regulations designed for other levels. The result of this situation is a vacuum linked to the eradication by the administration of the revealed religions of customary laws, religious beliefs upon which were based a number of behaviors and attitudes conducive to the sustainable management of natural resources and the rejection of modern formal laws. In this context, no one feels implicated nor do they feel they have the power, nor the legitimacy to regulate or prohibit access to resources which, in their eyes, is devoted solely to agents of the state. (translation) (Kremer and Mbodj 2003: 2)

This led to the establishment of a multi-standard system, in which the laws clash and/or are interspersed depending on the legislative body involved. In this type of situation, people act according to a code of laws which they consider legitimate, traditional laws, but in relation to which they are often placed in a position of illegality vis-à-vis the standards of the States (Lavigne Delville 1999).

Many practices related to the prevalence of *customary laws* or *local land tenure systems* have been identified, particularly with regard to clearing and logging. Although there is a regulation on land clearing, villagers work more often than not with land without holding a permit.[3] Community harmonization of land ownership is based principally on traditional or customary laws, and not according to state laws. This is also the case for the license to cut wood. Although a permit is required, many suggest that illegal logging is performed daily. "In a way and according to some analysts, it is just the symptom of a more serious problem facing Senegal's society: that is the gap between an authority lacking in representation and the population" (World Bank 2010: 38). Because local authorities often do not possess the legitimacy and a system of constraints well-enough established to require compliance with the standards developed in forestry codes and regulations at the national level. This therefore leads more often than not to irrational land clearing and degradation, thereby accentuating the decline in agricultural production and the risk of food insecurity (World Bank 2010).

---

[3] "From this fact, legitimate rights according to the social logics of a particular territory have no legal recognition. Rural populations are maintained in a position of permanent illegitimacy and judicial insecurity, particularly in the forestry sector, where the discrepancy between the law and the logic of the exploitation based on the local milieu is the largest. Thus, such populations can be subject to penalties for having recultivated fallow land, or risk seeing their lands allocated to others via the process of immatriculation." (translation) (Lavigne Delville 1999).

12.5 Vulnerabilities, Coping Strategies, Capacity Building and Climate Resilience

12.5.1 Socio-environmental Vulnerability of Rural Communities in the Department of Bakel

According to the IPCC, vulnerability is defined as a combination of risks, impacts and adaptive capacity. "Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of *climate change*, including *climate variability* and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its *sensitivity*, and its adaptive capacity" (IPCC 2007). The degrees of vulnerability vary across regions, populations and different climates. Some areas, however, are more sensitive than others. From a social perspective, the modification of and the precarious access to essential goods such as food, water, energy and housing, double the risk of vulnerability (United Nations 1992a).

In Senegal, the causes of vulnerability of populations and natural systems must be analyzed from the perspective of a "double window" or from both an environmentalist and socio-political perspective. The so-called underlying causes of vulnerability, as designated by the World Bank, are affected by the socio-economic and socio-political structures, as well as the balance of power, inequality and the law (World Bank 2010).

Rural communities in the Department of Bakel that are considered among the most affected by climate change impacts local are now confronted daily with unreliable access to water resources as well as an environment that has been highly degraded by unplanned transhumance, deforestation and bush fires. For the vast majority of the 200,000 inhabitants engaged in farming and animal husbandry, socio-ecological vulnerabilities result in a reduction in crop yields, the risk of food insecurity, the prevalence of poverty and unbalanced access, mainly for women, to education and information (Lead Afrique Francophone 2009b).

12.5.2 Adaptation Strategies

Faced with climatic stress and environmental challenges, the populations in rural communities in the Department of Bakel, who have a strong sense of community solidarity, will not, however, remain without taking action. With a rich indigenous knowledge, they are developing adaptive strategies to minimize the risks associated with these phenomena and to ensure that their work commitment is not further degraded (World Bank 2010). "Adaptation has become a buzzword. However, since the major drought years of the 1970s the rural population of Senegal and the Sahel have begun to develop alternatives to ensure a minimal production" (Défi Sud 2008: 22).

By focusing on the adoption of adaptation strategies, defined by the IPCC as the "adjustment in natural or *human systems* in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007), the populations in the Department of Bakel have been reducing the vulnerabilities they face.

Adaptation can be particularly effective for the dissemination, popularization and democratization of information to vulnerable populations, as well as contributing to the support and capacity building of local actors in the development of concrete actions, including through the promotion of multi-sectoral cooperation (UNFCCC 1992).

12.5.3 Reinforcing Capacities

As part of its project on building the adaptive capacity of civil society to deal with the effects of climate change, the NGO Lead Francophone Africa is involved among other things in strengthening the capacity of local actors in ten communities in the Department of Bakel and is promoting a strategy of ecosystem adaptation to rural communities. This method promotes resilience, capacity building and income diversification through the introduction of a multi-sectoral approach, in which the local population, government, and private and community stakeholders work together. The emphasis is on information dissemination, education, knowledge transfer and training of local actors (Lead Francophone Africa 2008).

It is understood that capacity building includes all measures to be implemented to ensure that individuals, institutions and systems are better able to make decisions and to implement and carry out their duties effective, efficient and sustainable manner (UNFCCC 1992). At the individual level, this approach attempts to positively change the behavior or attitudes through technical knowledge transfer, training, education, participation and exchange, thus ensuring that the individual will have awareness increased so that he or she will appropriate the basic tools. In an institutional context, this approach is adopted in order to create an efficient organizational environment and to create adaptation tools that can be deployed in situations involving change. For systems, capacity building promotes the transfer of knowledge and communication between the different agencies. Learning through practice, education and awareness are the main techniques adopted in this approach (UNFCCC 1992).

12.5.4 Local Adaptation Strategies in Rural Communities in the Department of Bakel

> However, the population does not easily adapt to its natural environment, it modifies it by adopting a wide range of flexible technologies. Poor producers living on more fragile land have accumulated centuries of experience in natural environmental management under a risk; which helps them in identifying and experimenting new technological options. (World Bank 2010: 22)

The set of non-exhaustive adaptation strategies presented below have been developed in various rural communities in the Department of Bakel.

12.5.4.1 Diversification

To overcome the negative impact engendered by land degradation and the effects of climate change on agricultural production, farmers adopt foremost strategies of diversification. The introduction of new crops such as sorghum, maize and groundnuts, the adoption of short cycle cultivars, the relocation of some crops and the practice of market gardening in rainy conditions alternating according to the seasons, are among the strategies that are involved. In addition, women diversify their activities by breeding small ruminants for sale as well as the management of cereal banks. This diversification provides additional food supply and provides additional financial resources, as well as contributing to the empowerment of women (Lead Afrique Francophone 2009a).

12.5.4.2 Innovations

In relation to vulnerability to shorter seasons and timing of cultivation, agricultural and technological innovations are valued by the villagers as they facilitate the management, planning and control of resources. By introducing micro dams to retain water longer in pools and backwaters, villagers have mastered a hydro-agricultural technique, which can delay a drought by a few weeks and thereby optimize agricultural yields. Farmers also use techniques of spreading organic manure to fertilize the soil and farmers now prefer small ruminants (sheep and goats), because these animals are more resistant to extreme weather conditions.

The introduction of market gardening crops also represents an agricultural innovation supported by villagers. This new activity is helps confront certain environmental, logistical and technical challenges. In environmental terms, market gardeners must often juggle with insufficient water resources and the presence of parasites. In terms of logistics, water pumps often fail and access to tools has often become a source of complications. On the technical level, staff often lacks training and the control of cultivation techniques are not always up to par. In all, once all of these difficulties are completely mastered, crop rotation can guarantee better promote agricultural production and favors food security (Lead Afrique Francophone 2009a).

12.5.4.3 Actions Restoration and Protection of Natural Resources

In terms of the community plan, land use planning, re-vegetation, the reintroduction of native species, reforestation, and the establishment of firewalls are the main actions undertaken by the community to restore biodiversity. At the same time, villagers have built micro-irrigation systems in strategic areas to reduce erosion and the effects of land degradation.

In addition, village committees have been established to ensure the exchange of information between local authorities and the population. As representative units of civil society and as local leaders, these committees prioritize actions to protect and restore ecosystems and fight against the degradation of biodiversity and unlawful actions. The ultimate goal of these committees is to reduce the environmental footprint of the community by educating people about the adoption of sustainable practices in their domestic and economic activities.

Their actions are realized through advocacy, and through environmental education and consultation centered on the sustainable use of natural resources. Village committees animate sessions including community consultations and awareness building about the scarcity of resources and citizen empowerment. In addition, the committees function to ensure respect of the system of penalties constructed from the community rules for the management of natural resources. This system facilitates the monitoring and protection of resources, including regulating logging and hunting a particular areas. Village committees attempt therefore to promote the sustainable management of resources, by ensuring the planning, regulation and monitoring of protected areas (Lead Francophone Africa 2009).

12.5.4.4 Reconversion

In a situation of dependency and vulnerability in the face of the steady decline of fishery, agricultural and animal stocks, traditional labor has no other choice but to expand its horizons for work. In the rural communities concerned, it has been observed that resilience faced with climate shocks has been reinforced among households who received outside income. When it has been possible, international migration has been the first alternative considered as international migrants do benefit both their families and their community of origin, including investing in social infrastructure and basic amenities (Lead Francophone Africa 2009).

For people who remain, reconversion in the market gardening domain, construction and services, including the sale of essential commodities and sale of small ruminants, are the most frequent activities. For example, it is not uncommon for a farmer to reconvert to the raising of small ruminants. This reconversion strategy is practiced and valued because it adds value to the work force and earn additional.

"According to a recent report, households where agriculture is the main source of revenue earn CFAF 41,000 per month on average, whereas in households which combine agriculture with another activity, the average monthly income is in excess of CFAF 60,000" (World Bank 2010: 21).

12.6 Climate Resilience

Through these adaptation strategies, agricultural production is increased, and becomes more valued and more profitable. Food security is enhanced. In addition, the technical and organizational capacities of local communities are strengthened, and this is especially thanks to the existence of new sources of information. Being better informed and aware of the impacts of climate change and human activities, people now favor the adoption of more sustainable behavior and attempt to optimize the use of natural resources in order to reduce the environmental footprint of their community. Through these coping strategies, new solidarities are also created within communities, fostering a sense of self-esteem and personal fulfillment. A positive group dynamic leads to the establishment of new forms of local initiatives.

Climate resilience of the people in the Department of Bakel is strengthened by these adaptation strategies that contribute to a sustainable reduction of their vulnerability to the impacts of climate change, while enhancing their leadership and empowerment.

However, these strategies are not sufficient to overcome the internal malfunctioning of institutions of decentralization, which contribute to an increase in the degradation of ecosystems. In addition, access to finances will also, as a first measure, ensure the upkeep and maintenance of community infrastructure such as boreholes, cemented wells, equipment and pumps, all of which are not unsubstantial elements in the development of adaptive responses and the improvement in people's living conditions, especially for the most vulnerable families (Lead Francophone Africa 2009).

12.7 Conclusion

The rural populations of Senegal, considered among the most vulnerable actors in relation to climate change impacts both environmentally and socially, are now inevitably faced with unprecedented environmental challenges. "For them, adaptation is a matter of sheer survival." (Annan 2006) and they engage their local knowledge in order to reduce, even if by a small amount, their precariousness. However, these adaptation strategies also require state support, both financial and socio-political, so that sustainable solutions are developed to deal with these environmental changes at both local and national levels.

Thus, adaptation strategies will be reinforced if, as set out in Principle 10 of the Rio Declaration on Environment and Development, human rights, including access to information, the opportunity to participate in decision-making, access to education and non-discrimination are ensured. These all facilitate individual and collective resilience, influence the development of sustainable solutions and encourage States to respect fundamental rights at national, regional and local levels. Ideally, vulnerability to environmental disturbances will be reduced and communities will have the possibility and capacity to be agents of change in the face of climate change (CIFOR, IUCN 2011).

At the political level, the integration of the concepts of sustainable development, mitigation and adaptation in policies and national and local laws, including those dealing with the management of natural resources and protection of the environment, allow the State and local communities to be better able to cope with current and future challenges that are represented by climate change over the coming decades (FAO 2011).

References

Center for International Forestry Research (CIFOR) and International Union for Conservation of Nature (IUCN). (2009). *Rights-based approaches: Exploring issues and opportunities for conservation* (Electronic version). Retrieved August 26, 2011, from: https://portals.iucn.org/library/efiles/edocs/2009-014.pdf

Défis sud (2008, September). *Dossier Réchauffement climatique: Zéro degré de responsabilité des pays pauvres!*, n° 84- Bimestriel – août (Electronic version). Retrieved August 27, 2011, from web site: http://www.sosfaim.be/pdf/publications/defis_sud/84/defi84_complet.pdf

Diop, M. (2009). *Energy systems vulnerability – Adaptation – Resilience, Senegal* (Electronic version). Retrieved August 26, 2011, from:http://www.helio-international.org/VARSenegal.Fr.pdf

Food and Agriculture Organisation (FAO) United Nations (2011). *Dossier sur le changement climatique à l'intention des décideurs. Une approche pour intégrer la dimension du changement climatique dans les programmes forestiers nationaux à l'appui de la gestion durable des forêts* (Electronic version). Retrieved September 13, 2013, from: http://www.fao.org/docrep/015/i2429f/i2429f00.pdf

Intergovernmental Panel on Climate Change (IPCC). (2007). Climate change 2007: Working Group II: Impacts, adaptation and vulnerability. Glossary (Electronic version). Retrieved August 25, 2011, from: http://www.ipcc.ch/publications_and_data/ar4/wg2/en/annexessglossary-a-d.html

International Energy Agency (2008). *World energy outlook* (Electronic version). Retrieved August 25, 2011, from:http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo2008.pdf

Kremer, W., & Mbodj, S. (2003). Senegal. Minister of environment and sanitation. *Local conventions: A tool for good governance, a way to reconcile with the modern common law right* (Electronic version). Retrieved August 25, 2011, from:http://www.environnement.gouv.sn/IMG/pdf/concept-conv-locales.pdf

Lavigne Delville, P. (1999). *Comment articuler législation nationale et droits fonciers locaux: Expériences en Afrique de l'ouest francophone*, Dossier Zones arides n°86, Londres, IIED, 31 p (Electronic version). Retrieved August 27, 2011, from: http://www.gret.org/ressource/pdf/articuler_legislation_nationale.pdf

Lavigne Delville, P. (2002). *Vers une articulation des modes de régulation foncière? Avancées ré centes et enjeux (Afrique de l'ouest francophone)* (Electronic version). Retrieved August 26, 2011, from: http://www.ruralforum.info/2007/papers/lavignedelville3fr.pdf

Lead Afrique Francophone. (2008). *Rapport sur le zonage et les caractéristiques des communauté s rurales sélectionnées pour l'étude de référence dans la zone de Bakel.*

Lead Afrique Francophone. (2009a). *Étude de référence dans la zone d'intervention du projet Lead sur les changements climatiques dans le département de Bakel: Résultats et recommandations.*

Lead Afrique Francophone. (2009b). *Montrer la voie: Un rôle pour les institutions régionales africaines. Pour un leadership africain sur la question des changements climatiques en Afrique.*

Ross-Béthio. (2007). *Forum laws governing the decentralized management of the environment and natural resources* (Electronic version). Retrieved November 3, 2011, from: http://www.cse.sn/gdrn/documents/Forums/Rapport%20forum%20Ross_bethio.pdf

Senegal. (1996). Local development and decentralization in Senegal. *Law N° 96-07 du 22 mars 1996* (Electronic version). Retrieved November 3, 2011, from: http://www.sendeveloppementlocal.com/LOI-N-96-07-DU-22-MARS-1996-portant-transfert-de-competences-aux-regions-aux-communes-et-aux-communautes-rurales_a527.html

Senegal. (2006). Minister of environment and natural protection. *National action plan for climate change adaptation* (Electronic version). Retrieved August 25, 2011, from http://unfccc.int/resource/docs/napa/sen01f.pdf

Senegal. (2008). Minister of environment, natural protection, retention ponds and artificial lakes. *Local governance and decentralized management of natural resources in Senegal.General report of the Conference* (Electronic version). Retrieved August 25, 2011, from: http://www.cse.sn/gdrn/documents/Etudes/Rapport_colloque_fin.pdf

Senegal. (2010). Minister of economy and finance. *Millenium development goals. Progress and prospects* (Electronic version). Retrieved August 25, 2011, from: www.undp.org.sn/index.php?option=com_docmanandtask

United Nations. (1992a). General assembly. *Report of the United Nations conference on environment and development* (Electronic version). Retrieved August 26, 2011, from: http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm

United Nations. (1992b). *United Nations framework on climate change*. (Electronic version). Retrieved August 26, 2011, from: http://unfccc.int/resource/docs/convkp/conveng.pdf

United Nations. (2006). *Secretary general Kofi Annan, 12th conference of the parties to the United Nations framework. Convention on climate change, 2006, Nairobi, Kenya* (Electronic version). Retrieved August 26, 2011, from: http://www.un.org/press/en/2006/sgsm10739.doc.htm

United Nations. (2010). United Nations development program, Senegal. *National report on human development. Climate change, food security and human development* (Electronic version). Retrieved August 26, 2011, from: http://hdr.undp.org/fr/rapports/national/afrique/senegal/RNDH_Senegal_2010.pdf

World Bank. (2010). *Local development, institutions and climate change in Senegal* (Electronic version). Retrieved August 25, 2011, from World Bank web site: http://siteresources.worldbank.org/EXTSOCIALDEVELOPMENT/Resources/244362-1232059926563/5747581-1239131985528/5999762-1242914244952/Senegal_Report_Final_EN.pdf

Gabrielle Tremblay holds a Master degree in International Studies from the University of Montreal and a BA in Sociology from the University of Quebec in Montreal. Her main research interests are in climate change vulnerabilities, climate change adaptation, climate resilience and gender equality in developing countries. She has worked as a Climate Change and Sustainable Development Officer for Oxfam and as a Gender and Sustainable Development Coordinator for Canada World Youth. She is currently working for the International Bureau of Children's Rights as a Monitoring and Evaluation Manager.

Chapter 13
Adaptations of the Agricultural Calendar and Agricultural Techniques to Climate Change in the Highlands of Cameroon

Feumba Rodrigue Aimé, H. Blaise Nguendo-Yongsi, Christopher R. Bryant, Chétima Boukar, and Cyrille Tuekam Tueche

Abstract From its inception with regard to climate change, scientists, stakeholders and policymakers did focus their efforts predominantly on mitigation. But since a decade now, efforts of the international community deal with adaptation, this being both a matter of need as climate change is now underway and a matter of equity as its impacts fall disproportionately worldwide. Climate change adaptation refers to actions that reduce the negative impact of climate change, while taking advantage of potential new opportunities. It involves adjusting policies and actions because of observed or expected changes in climate. Future impacts (if they are yet to be obvious) will affect a broad array of human and natural systems, including areas vital to economic and social well-being, such as agricultural. In fact, production of food crops is the most climate-dependent economic activity and changes in climate are expected to have significant impacts upon crop yields through changes in both temperature and moisture. Therefore, anticipating and adapting to these impacts in

F.R. Aimé (✉)
Higher Teacher's Training College, The University of Yaounde I, Yaounde, Cameroon
e-mail: rfeumba@yahoo.fr

H.B. Nguendo-Yongsi
Institute for Training and Research in Population Studies, University of Yaoundé II, Yaounde, Cameroon
e-mail: sir_nguendoyongsi@hotmail.com

C.R. Bryant
University of Montréal, Montréal, QC, Canada

School of Environmental Design and Rural Planning, University of Guelph, Guelph, ON, Canada
e-mail: christopher.robin.bryant@gmail.com

C. Boukar
Lake Chad Programm (GIZ/CBLT), N'Djamena, Chad
e-mail: boukar.chetima@giz.de

C.T. Tueche
Department of Geography, The University of Yaoundé I, Yaounde, Cameroon
e-mail: tuechecyril@yahoo.fr

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_13

order to minimize their human and environmental toll is a significant challenge for all. Objective: As meeting that challenge requires action at multiple levels, from the international to the local this paper explores and evaluates the forms of adaptation of the agricultural calendar and cultivation techniques used to improve corn production in the context of family farming in Bantoum. Method: Data used here derive from field investigations conducted in the area in 2012. We did resort to both qualitative (participant observation) and quantitative (use of standardized questionnaires) techniques to collect data from the farmers. However, rainfall data came from the Bangangté forecasting station located 10 km from our study area and which has a similar climate based on the extent of the data series from 1980 to 2010. To highlight the surplus or deficit years, index of rainfall anomaly was calculated based on the Ozer and Erpicum method (Sècheresse 6(1):103–108, 1995). Priority was given to the historical approach in order to capture changes to the agricultural calendar and corn production techniques over the years in the area. Results: This research highlights a strong inter-annual and seasonal variability of rainfall volumes which is detrimental to a good corn production in Bantoum. To come accross shortage of rainfalls, Bantoum farmers have modified their agricultural calendar by gradually abandoning the minor rainy season for cultivation in favor of a new production campaign, and by setting up a campaign during the long dry season in the swamps by using irrigation.

Keywords Climate change • Seasonal variability • Adaptation • Family agriculture • Bantoum • Cameroon

13.1 Introduction

In Bantoum[1], a rural setting situated in the western Cameroon Region between 5° 1′ and 5° 11′ latitude North and 10° 35′2″ and 10° 51′8″ longitude East (Fig. 13.1), the dominant tropical climate sub-type is that of the sheltered mountain monsoon. The seasonal rainfall variability is very pronounced. Generally, there are four seasons: the short rainy season from March to June, the short dry season in July, the major rainy season from August to October and the long dry season from November to February (Suchel 1988; Tsalefac 1999; Feumba 2001). For a long time, farmers in the area were growing seasonal food crops under rainy conditions, notably corn[2]

[1] In this chapter, Bantoum refers to the southeastern sector of the District of Bangangté in the Department of Nde, Western Region, Cameroon. This area includes the villages where people have settled spontaneously for centuries and pioneer villages created by the State in the early 1980s as part of a land settlement project called the *Projet Route du Noun* (PRN).

[2] With the scientific name *Zea mays*, corn is a herbaceous tropical plant of the Poaceae family (grasses). It is widely cultivated as a cereal for its rich grain starch, but also as fodder. Corn is a demanding crop in terms of water. Corn that is 120 days old in a tropical climate requires at least 600 mm of well distributed rainfall. Climate stress has consequences on yields. Droughts are particularly damaging at planting time, but even more so at the time of flowering and the formation of cobs. Excess rainfall causes suffocation, root rot and winds cause lodging (Mbangue 2009; Batha 2011; Tuekam 2012).

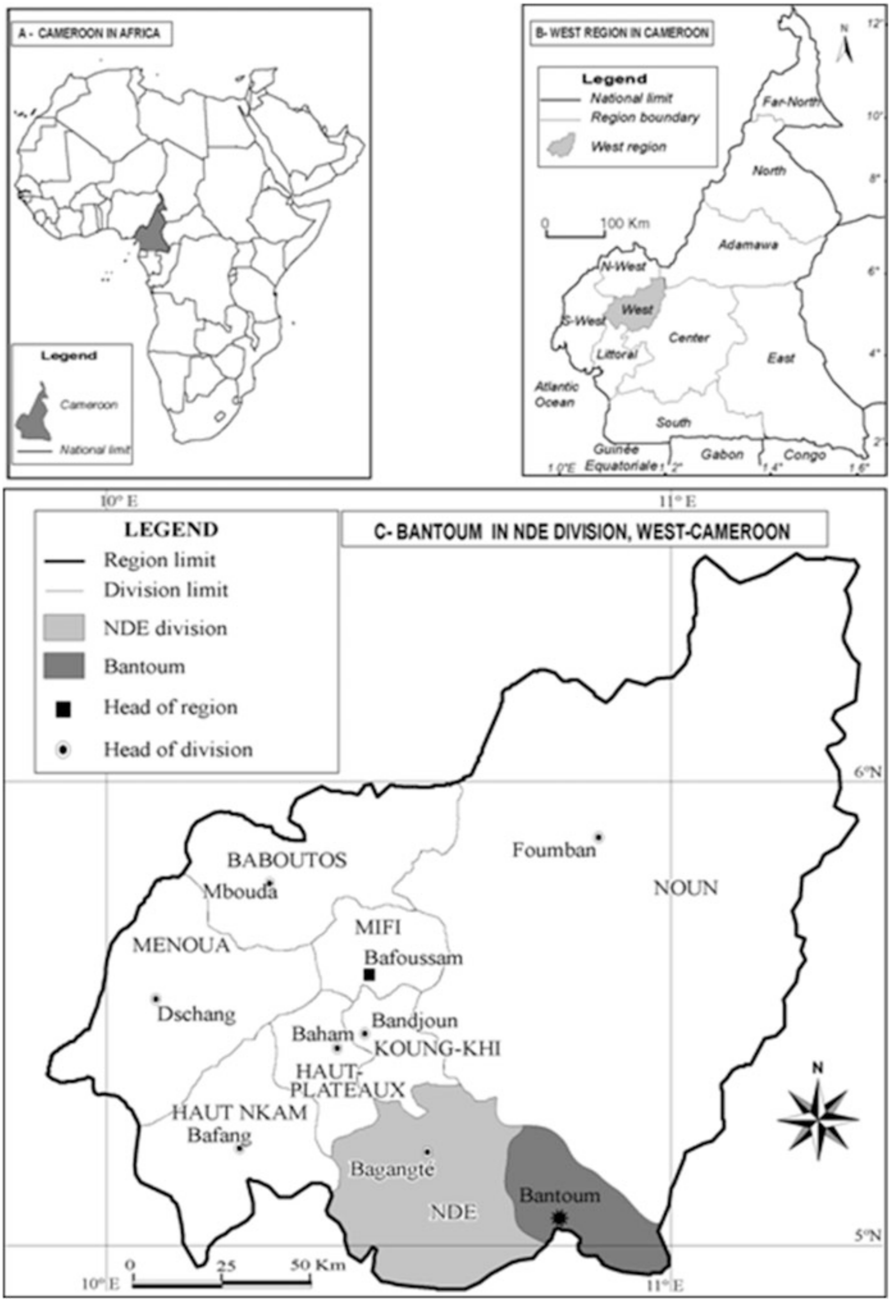


Fig. 13.1 Location of Bantoum in the Department of Ndé, Cameroon

during a single season, from March to June (Nganso 1982; Feumba 2001). It should be noted that corn, the only cereal grown in the area, occupies a particular place in people's diet. Moreover, the surplus production is sold as this product is increasingly sought for cattle breeding and for breweries. Also, since the early 1990s corn has become a market-oriented food product produced by small farmers to replace coffee or cocoa which experienced poor sales and which were one of the causes of the economic crisis of the late twentieth century (Kouam 2006). Unfortunately, when corn was generating considerable income for small farmers, climate variability and change (CVC) was becoming more and more significant to the point where it had been seriously hindering its production in Bantoum for close to 20 years. Indeed, a late start of the rainy season was frequently observed that disrupted the agricultural calendar, with false rainy season starts followed by long dry spells that caused the destruction of corn seeds that had been planted too early or that caused the wilting and sagging of young plants. In addition, the corn fields experienced low amounts of rainfall which was increasingly observed from March to June, and thus their growth cycle became perturbed leading inevitably to low yields, to lower production levels, and thus to a food deficit and to declining incomes for small farmers faced with many family responsibilities. The objective of this chapter is to evaluate forms of adaptation of the agricultural calendar and cultivation techniques used to improve corn production faced with the impacts of CVC in the context of family farming in Bantoum.

13.2 Methodology

In order to study CVC at the inter-annual level, we used rainfall data from the Bangangté forecasting station located 10 km from our study area and which has a similar climate based on the extent of the data series from 1980 to 2010 (DAADER[3] 2010). These data allowed us to analyze the trend and the phases of the inter-annual changes in precipitation based on the calculation of moving averages. To highlight the surplus or deficit years, we calculated the index of rainfall anomaly. The latter is defined as a standardized variable expressed by the equation $Ii = \frac{Xi - \overline{X}}{S}$ with Xi being the value of annual rainfall, $\overline{X}$ the average inter-annual rainfall for the period from 1980 to 2010, and S being the inter-annual value of the standard deviation of rainfall over the period 1980–2010. Then, we use the terminology that Chapman used for the study of drought during the 1980s and subsequently used in Cameroun by Kemche (1991), Feumba (2001) and Tuekam (2012) to characterize the levels of rainfall surpluses and deficits. Thus, in terms of the level of deficit years located below the mean, this analysis differentiates three levels of drought:

[3] *Délégation d'Arrondissement de l'Agriculture et du Développement* Rural (Sub-District Delegation for Agriculture and Rural Development).

- If the absolute value of the difference in rainfall from the average is less than the standard deviation, the drought is said to be **normal**.
- If the absolute value of the difference is greater than the standard deviation and less than twice the standard deviation, the drought is said to be **moderate**.
- If the absolute value of the difference is greater than two times the standard deviation, the drought is categorized as **serious.**

In terms of number of years with rainfall greater than the average, this terminology allows us to identify three different levels of humidity:

- If the number of years with excess rainfall above the average is less than the standard deviation, the year is said to have a **normal** level of humidity.
- If the level is greater than the standard deviation and less than the standard deviation, the year is labeled as having a **moderate** level of humidity.
- If the difference is greater than two times the standard deviation, the year is labeled as having a **serious** level of humidity.

Variability and changes at the intra-annual and seasonal scale were analyzed on the basis of daily rainfall data from the Bantoum station (2006–2010) based on the number of days of rain and calculating the monthly rainfall index using the equation $\frac{pi}{P}$ (with pi being the monthly rainfall level and P the average monthly rainfall). A month is said to be wet if the ratio is greater than 1 and dry if it is the opposite. This analysis also refers to the formula of Birot, used by Feumba and Tsalefac (2006).

The study of false starts of rainfall, of the variability of the start and end dates of the rainy season as well as of intra-seasonal drought was based on the method of Ozer and Erpicum (1995), and the work of Mbaye (1996) and Van Vyve (2006). The method of Ozer and Erpicum states that the rainy season essentially begins when the probability of having a rainy day during a 5 days period (called a 'pentade'[4] in French) is higher than that of having a dry day belonging to a dry period of more than 7 days. The days with rainfall ≥ 1 mm are counted by 5 days periods from March 1st to October 31st. This also lets one search for dry spells greater than or equal to 5 days.

Calculation of the linear correlation coefficient has allowed to link several variables such as the number of rainy days and rainfall levels, rainfall and corn production.

Farmers' perceptions of CVC, impact of these disturbances on corn cultivation, assessment of the vulnerability and farmers' adaptation strategies were discussed on the basis of the qualitative and quantitative analysis data from observations in the cornfields on several production campaigns in 2011 and 2012 together with the surveys and interviews with 88 farmers and other key stakeholders in the corn production chain following the recommended approaches in this area (UNDP 2005; GIEC 2007; C.I.A.T 2008; De Perthuis et al. 2010). Priority was given to the

[4] This refers to a series of five continuous days.

historical approach on order to capture among other aspects the changes to the agricultural calendar and corn production techniques over the years in the area.

13.3 Demonstration of Rainfall Variability and Change in Bantoum

13.3.1 Inter-annual Rainfall Variability

Figure 13.2 presents the evolution of rainfall at the Bangangté station from 1980 to 2010. The curve shows two major extremes and four minor or secondary ones. The major minimum one corresponds to the year 1987 (n° 8 on Fig. 13.2) in which the lowest annual rainfall of 993 mm was recorded. This was certainly the year of great drought during which several pioneers of PRN[5] and corn producers abandoned cultivation and sometimes left the area (Kouam 2002, 2006; Tuekam 2012). The main maximum event was in 2001 (n° 23 on the figure) when the largest annual rainfall of 1824.2 mm was recorded. The two secondary minima correspond to the years 1990 and 1992 with cumulative rainfall around 1050 mm per year. The two secondary maxima correspond to the years 1999 and 2007 with more or less equal rainfall amounts of about 1600 mm per year. The calculation of the moving average allowed us to highlight five periods of rainfall between 1980 and 2010:

- Two relatively stable periods: from 1980 to 1987 and from 1994 to 2001
- A deficit period: from 1987 to 1994
- A surplus period: from 2001 to 2007
- A relatively stable period with a downward trend: 2007 to 2010.

Based on the calculation of annual rainfall indices (Fig. 13.3), in the 30 year period studied, Bantoum's area shows three periods of surplus rainfall respectively from 1983 to 1986, from 1997 to 1999 and from 2001 to 2004. We note furthermore the presence of wet years interspersed in the periods with rainfall deficit. This is the case for 1981, 1995, 2007 and 2009. All these surplus years present mostly normal levels of humidity with the exception of 1999, 2002 and 2007 with moderate humidity and 2001 with severe humidity with a rainfall of 1824 mm.

Over the last 30 years, the area has experienced deficit years or periods in terms of rainfall. The largest deficit period was from 1987 to 1994. The year 1987 saw a major change from rainfall of 1400 mm per year on average to rainfall which is now around 1000 mm/year. This was a year of almost serious drought. 1990 and 1992 were years of moderate drought. Other years can be characterized as years of normal drought. They break up sometimes periods of surplus to normal humidity.

[5] *Projet Route du Noun*. This is a project initiated in the study area by the Cameroon government in the early 1980s to install and support the pioneers in agricultural production in the plain of Noun (Kouam 2002, 2006; Tuekam 2012). There are two pioneers villages: PRNI and PRN II.

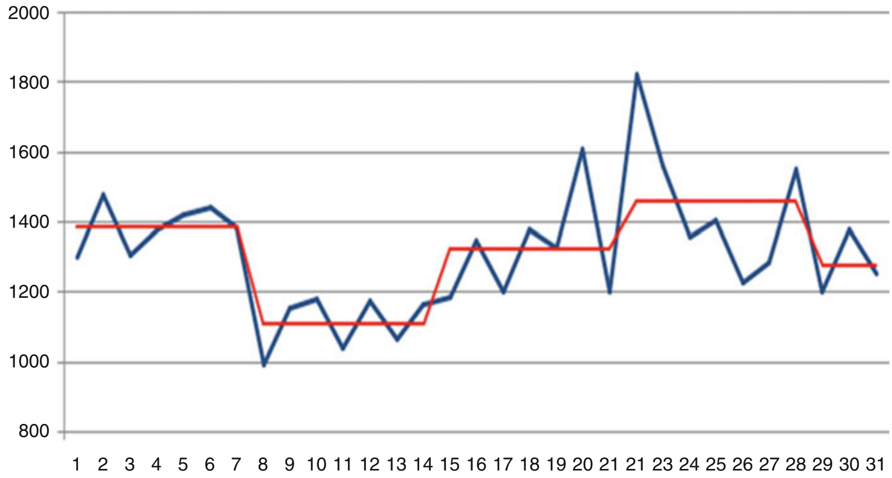


Fig. 13.2 The evolution of rainfall from 1980 to 2010 at Bangangté

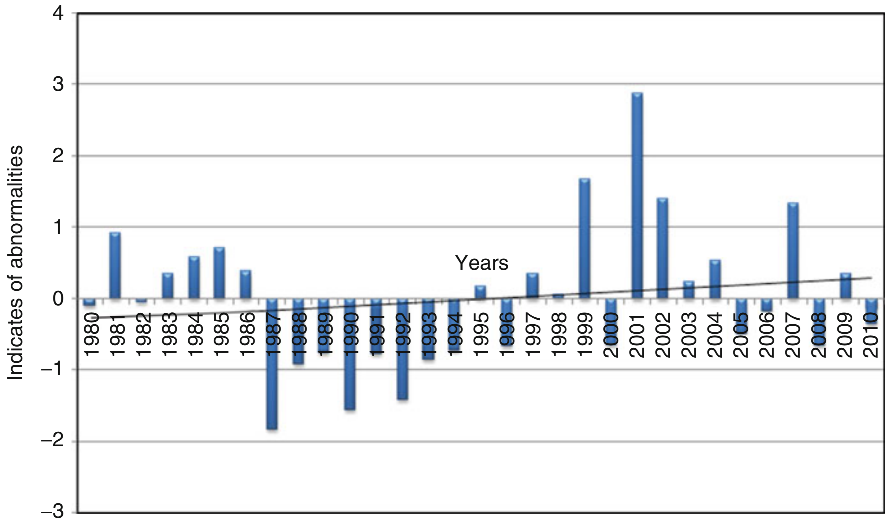


Fig. 13.3 Index of rainfall Anomaly from 1980 to 2010 (Source: DAADER 2010)

The major disruptions in rainfall can also be seen through this juxtaposition between surplus and deficit years. This is the case for the years 1999, 2000 and 2001 (when rainfall levels went from more than 1600 mm to 1200 mm, and then rebounded again to over 1800 mm). From 2004 to 2010, years of deficit and years of surplus followed each other on an annual basis, and sometimes biannually but with a clearly discernible wet trend.

Changes in the number of rainy days have a high variability around the mean (Fig. 13.4). The average of the whole series is about 91 days of rain a year, but major differences are observed, i.e., a maximum of 121 days of rain in 1986 and a minimum of 72 days of rain in 2007. Unlike the annual level of rainfall, the general trend of the evolution of the number of rainy days per year is declining, going on average from 100 days per year between 1981 and 1991 to 90 days per year between 1992 and 2002 and then 79 days per year between 2003 and 2009. As can be seen, the last period (2003–2009) records a number of rain days per year less than the average for the whole series while from the perspective of annual rainfall, it appears as a surplus period in terms of humidity. Thus, there is a very low correlation ($r = 0.09$) between the number of days of rain and the level of annual rainfall. By way of illustration while 1986 recorded 1385 mm of rainfall in 121 days, 2007 recorded 1552.7 mm in 72 days. This inter-annual temporal variability highlights the contrast, with the dual hazard causing risks of corn cultivation, resulting in years with intense or heavy rainfall (cumulative rainfall above average) alternating with periods with a number of days with rainfall below the average, i.e., rainfall which is very poorly distributed over the year. This phenomenon has been particularly observed since 2003, but it began in 1991, unlike years with less intense rainfall (i.e., below average rainfall levels) with numbers of days of rainfall above average observed during the 1980s and 1990s to a lesser extent.

13.3.2 Intra-annual Rainfall Variability

13.3.2.1 Study of the Rainfall Régime

The analysis of rainfall data recorded from 2006 to 2010 gives an average rainfall of 1136.4 mm per year with an overall monthly average of 94.7 mm (Fig. 13.5). The difference between the rainiest month and the one with the least rainfall is 225.4 mm. The curve highlights a bimodal situation with a secondary maximum in May (127.6 mm), and a main maximum in October (227 mm). The latter is more remarkable with a surplus of 177.3 mm above the overall monthly average. If one refers to the Birot formula that a month is said to be dry when $P \leq 4$ t (with P representing monthly rainfall and t the temperature), one can observe that Bantoum on an annual basis has 6 dry months: January (2 mm), February (22.5 mm), March (44 mm), July (86.5 mm), November (68 mm) and December (4.3 mm). However, the months of July and November are relatively less dry than the others. The monthly rainfall index indicates that the months of May (127.6 mm), June (121 mm), August (135.5 mm), September (202 mm) and October (272 mm) are wet, with surplus monthly rainfall being very noticeable in September and October.

The low rainfall that the area registers unlike other highland areas of West Cameroon is due in part to its geographical location; indeed, it is a bowl-like site with a double topographical shelter consisting of the Cameroonian ridge and North, West and South West mountain areas that surround it (the foehn effect). On the

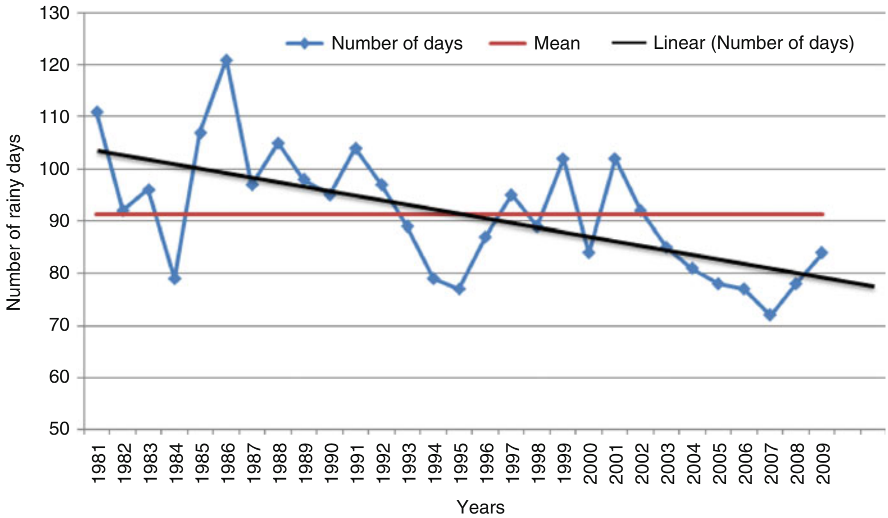


Fig. 13.4 Evolution of the number of rainy days at Bangangté from 1980 to 2010 (Source: DAADER 2010)

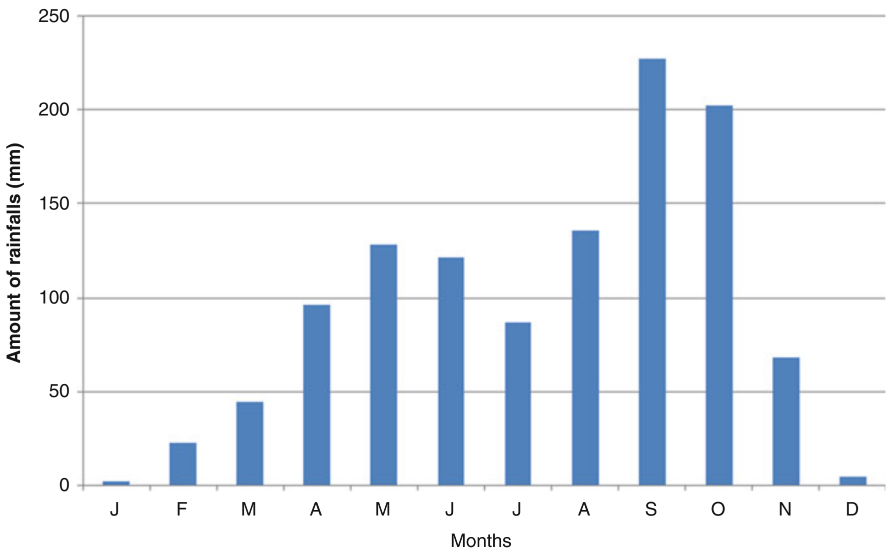


Fig. 13.5 Histogram of the average monthly rainfall for the period 2006–2010 (Source: DAADER 2010)

other hand, it is a transition zone between the sub-equatorial climate and the tropical monsoon climate, a situation which sometimes causes serious disruption of climate parameters. In addition, the rainfall deficits may also be explained by the movement of the Inter Tropical Front characterized by very irregular updrafts, reflecting successive incursions and withdrawals (Tsalefac 1999; Feumba 2001).

13.3.2.2 Monthly Rainfall Variability at Bantoum from 2006 to 2010

Between 2006 and 2010, Bantoum has experienced of great variability of monthly rainfall levels (Fig. 13.6). The year 2009 does not record any rainfall event during the month of March; however in August, September and October, it has the most significant rainfall records. Moreover, while August 2010 recorded 63.5 mm of rain, the years 2009 and 2006 in contrast had 257.5 mm and 107 mm of rainfall respectively, a respective difference of 194 mm and 43.5 mm. The month of October which is the main maximum with an average rainfall of 227 mm, recorded in 2007 127 mm of rain, a difference of 100 mm below the average. In summary, the months of August, September and October together account for the major contribution of rainfall in the area. This is most noticeable during the period 2003–2009 where one observes there to be more interest in cultivating corn during these three months because of the availability of storm water.

13.3.2.3 Study of the Beginning and End of the Rainy Season, and Dry Sequences from 2006 to 2010

This part of the study allows the detection of false rainfall starts, the variability of the start and end dates of the rainy season, and intra-seasonal droughts.

The analysis of the proportions of rainy days and dry days by 5-day periods from 2006 to 2010 shows that, unlike the years 2006 and 2009, the years 2007, 2008 and 2010 have had false starts to the rainy season. Bantoum registers an average of 3.4 dry spells of 5 days/year and 1.2 dry spells of 10 days in the rainy season. The dry spells of 10 days were recorded in 2006 during the month of August, in 2007 during the months of April, July and August, in 2008 during the month of May and in 2010 during the month of July.

The comparison of dates of the first and last rainfall on the one hand, and the effective start date and end dates of the rainy season on the other hand (Tables 13.1 and 13.2) identified by the method of Ozer and Erpicum shows considerable differences between the dates of the first rains and actual start dates of the rainy season in particular for the years 2007, 2008, 2009, 2010. These findings highlight the thorny problem of the false start of the rainy season. In contrast, the dates of the last rains almost always coincide with the dates of the actual end of the rainfall.

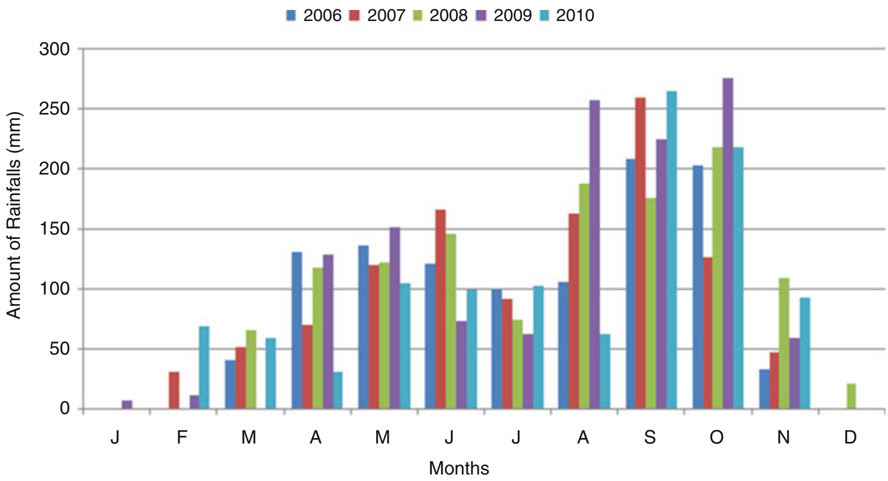


Fig. 13.6 Monthly rainfall levels recorded over the period 2006–2010 (Source: DAADER 2010)

Table 13.1 Comparison of the dates of the first rains and the rainy season start dates estimated by the method of Ozer and Erpicum

Years	2006	2007	2008	2009	2010
Date of the first rainfall	28 March	22 February	6 March	21 February	10 February
Date of the effective start of the rainy season	28 March	26 March	22 April	5 April	19 April
Number of days difference	0 days	33 days	46 days	43 days	57 days

Source: DAADER 2010

Table 13.2 Comparison of the date of the last rains and the dates of the effective end of the rainy season estimated by the method of Ozer and Erpicum

Years	2006	2007	2008	2009	2010
Date of the first rains	3 November	14 November	13 December	14 November	19 November
Date of the effective start of the rainy season	3 November	14 November	30 November	14 November	11 November
Number of days difference	0 days	0 days	13 days	0 days	8 days

Source: DAADER 2010

13.3.2.4 Study of Dry and Rainy Spells and Categories of Rainfall

The dry spells of 10 days or more between 2006 and 2010 were recorded on March, April, May, June and July and correspond to the minor rainy season and the short dry season.

In July (Fig. 13.7), they are greater than or equal to 2 during the months of March, April, June and July. The long rainy season which runs from August to October has no dry spells of 10 days or more, but records on a monthly basis more than 3 dry spells of over 5 days between 2006 and 2010. Of the 28, 44, and 39 dry sequences respectively recorded during the months of August, September and October, 85.71 %, 90.91 % and 84.76 % respectively are dry spells that constitute no damage to corn cultivation. Thus, this is the most appropriate time for growing this crop.

Figure 13.7 also shows that between 2006 and 2010, only the months of April, August, September and October recorded successive rainfalls of over 6 days. Rainy sequences longer than 4 days are concentrated in the long rainy season which runs from August to October. The short rainy season which runs from March to June

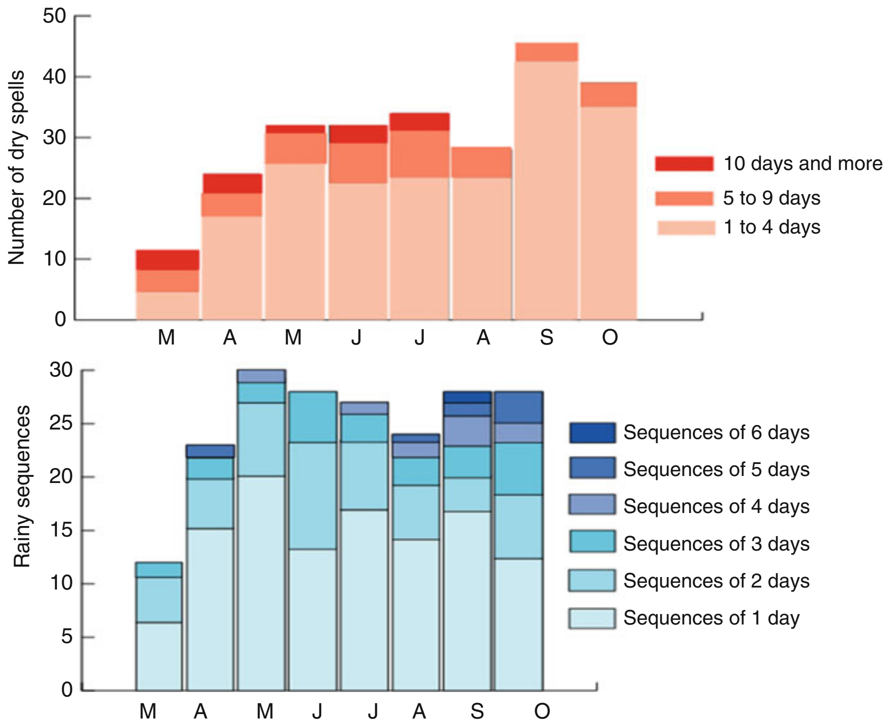


Fig. 13.7 Dry and humid sequences from March to October between 2006 and 2010 (Source: DAADER 2010)

shows a preponderance of rainy sequences of less than 4 days, with the exception of April that records sequences of 5 days.

13.4 Perceptions of Major Rainfall Hazards in Bantoum

To highlight farmers' perceptions of the impact of climate variability and climate change on corn production, we asked the 88 respondents who were surveyed to rank in order of importance the main problems they face in growing corn, to assess the frequency of rainfall hazards affecting agriculture, to present peasant's indicators of intra-annual variability in rainfall, and to suggest the reasons for climate disruption.

13.4.1 Classification in Order of Importance of Peasantry-Perceived Problems

Climate vagaries occupy a significant place among the main problems faced by peasant farming. Of the 20 corn farmers interviewed, 76 % consider them to be important or very important sometimes causing discouragement in corn production. According to them, problems like land insecurity, agro pastoral conflicts, expensive agricultural inputs and rudimentary equipment are less important regarding corn production.

13.4.2 Hazardous Rainfall Affecting Peasant Agriculture

After interviews with peasants on their farms, several rainfall hazards were identified, and the peasants ranked them according to their frequency of occurrence.

The irregular rainfall, the dry sequences in the rainy season, the late return of the rains, and false starts of rainfall are regularly observed by peasants (Fig. 13.8). At the forefront of the latter, the irregularities and dry spells are more pronounced and recognized as such by 73 % of the peasants interviewed. If regular rainfall and the late ending of rains are scarce, abundant and heavy rains are evident in the Bantoum area. To highlight the impact of climate hazards, all interviewees mentioned the great drought of 1987, which caused the departure of a hundred or so peasants who had settled in the area in the 1980s.

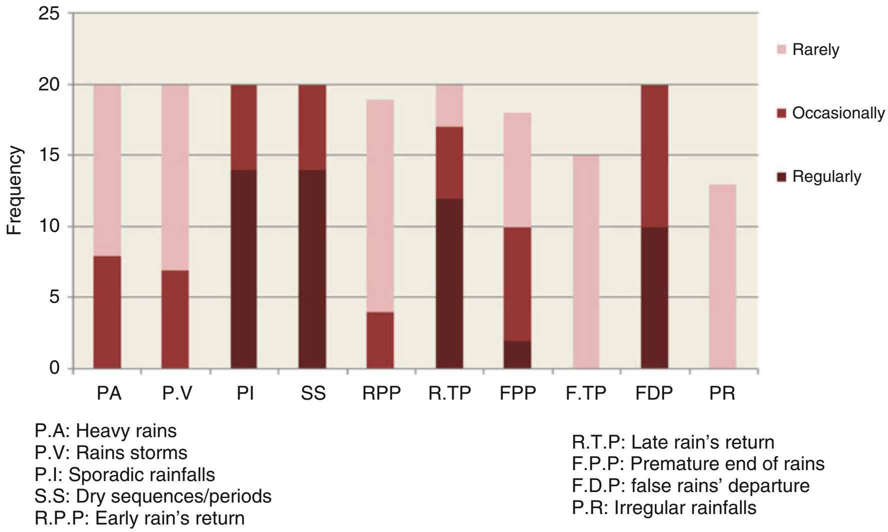


Fig. 13.8 Frequency of rainfall fluctuations according to peasants in P.R.N (Source: Field study)

Table 13.3 Exposure units in the production of corn in Bantoum

Exposure units in relation to rainfall hazards for the agricultural sector	Description of exposure units
Natural factors of production	Available water for crops, the soils at the base of any agricultural activity, seed capital
Human factors of production	Financial and human resources of production, field upkeep, inputs (fertilizer and seeds) and the agricultural calendar. . .
Crops	Corn fields
Infrastructures	Roads, tracks for collection of agricultural products, field cribs . . .

Source: Field survey, August 2011

13.4.3 The Main Exposure Units in Corn Production

The exposure units refer to any element of the physical, human, or organizational environment likely to be affected by rainfall hazards that can influence farming significantly. These exposure units are summarized in Table 13.3.

13.5 Impacts of Rainfall Variability on the Corn Crop

This study is conducted mainly on the seasonal and monthly scale because of the availability of data and the fact that the corn crop season lasts from three to four months. Some references are made to impacts on the inter-annual scale.

Through the surveys of Bantoum peasants we found that 97.7 % of them stated that their corn production activities are vulnerable to climatic hazards.

13.5.1 Impact of Dry Spells and Erratic Rainfall

Rainfall variability is translated at the intra-annual scale by the occurrence of intermittent dry spells. The 5-day period analysis of rainfall from 2006 to 2010 allowed us to highlight an average of 3.4 dry spells of 5 days per year and 1.2 dry spells of 10 days in the rainy season. Such a situation of irregularity and disruption of rainfall is not without negative consequences to the crops both in terms of their growth cycle, and in terms of yield and production levels.

Over 65 % of the 88 surveyed peasants believe that this situation of rainfall deficit seriously affects crops causing slower plant growth, malformation of grain and corn, early maturation, lower yields, in short, a decline in production (Fig. 13.9).

Indeed, corn suffers the harmful influence of dry spells. These are particularly damaging during the planting and especially during the vegetative stage (flowering, formation of cobs and pods). They cause a decrease in the percentage of fertilization and promote abortion of eggs and grains. Therefore, the years of deficit or

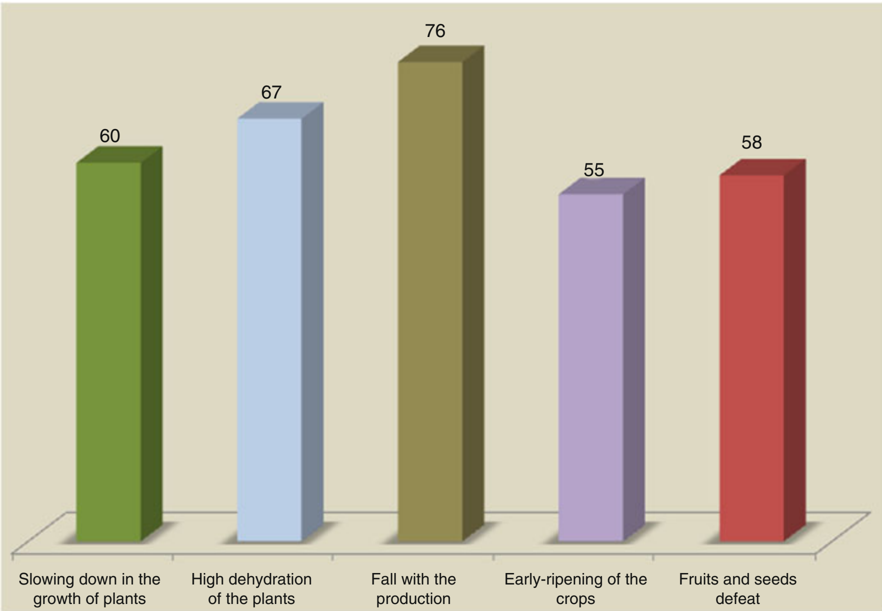


Fig. 13.9 Impacts of dry spells and irregular rainfall on food-producing farming according to the number of peasant farmers affected (Source: Field investigation 2013)

irregular rainfall (dry spells, false starts . . .) generally experience a drop in yield and production.

Figure 13.10 highlights the relationship between rainfall and the annual production of maize in the district of Bangangté. With a coefficient of correlation greater than 0.811, the two curves present a similar shape. They show a decline in production during the deficit years (2005, 2008) and production which increases with rainfall in the wettest years (2002, 2007).

13.5.2 The Incidence of Abundant and Heavy Rainfall on Corn Cultivation

The above study on rainfall variability, particularly rainfall sequences and categories of rainfall amounts, allowed us to identify the months of April, August, September and October, as periods of heavy and sometimes violent rainfall. The occurrence and intensity of these hazards seriously disrupts corn cultivation.

The observations confirmed by surveys of peasant farmers point out that they affect crops especially during periods of ripening and harvesting by causing the proliferation of fungal and bacterial diseases, the multiplication of leaf miners, caterpillars and leafhoppers. They cause suffocation, root rot and the spread of viral diseases such as *Corn streak virus, Fusarium moniliforme*, and promote the development of weeds that compete with crops for water and nutrients. Moreover they cause degradation of roads and collector trails and increase the risk of flooding,

Fig. 13.10 Evolution of rainfall and corn production in Bantoum from 2002 to 2010 (Source: DAADER 2010)

while heavy rains cause the collapse of crops, the destruction of rustic huts and soil erosion. Figure 13.11 shows photographs that illustrate certain aspects of this reality. On the left, one can observe the deterioration of the main road linking PRN II to the city of Bangangté after heavy rains; and on the right collapsing corn stalks in a field in PRN I following a violent rain storm.

13.5.3 Implications of False Starts and Late Return of Rains

False starts or late returns of recurring rains mislead farmers by disrupting the agricultural calendar and causing a loss of already insufficient seed capital. Approximately 77 % of the peasant respondents (Table 13.4) emphasize the loss of seed capital as the major consequence of false starts rains. In addition, the financial and human resources deployed for the maintenance of fields increases significantly.

In short, growing corn in Bantoum is seriously influenced by rainfall variability, which does not leave the peasants who grow corn indifferent. On a daily basis, they have to use different measures of adaptation to deal with different situations.

Fig. 13.11 Impacts of heavy and violent rainfall in P.R.N

Table 13.4 Impact of false starts and late return of rain on subsistence farming by the number of affected farmers

	Loss of seed capital		Perturbation of the agricultural calendar		Financial and human costs	
	No. of peasants	%	No. of peasants	%	No. of peasants	%
False starts and late return of rains	67	77.0 %	48	54.6 %	32	37.6 %

Source: Field survey

13.6 Peasants' Adaptation to Climate Change in the Cultivation of Corn

13.6.1 Development of Local Methods of Knowledge and Climate Prediction by Peasant Farmers in Order to Better Adapt

In Bantoum, there is no forecasting or communication system that educates peasant farmers about the climate on a daily or seasonal basis they will experience (rainfall patterns, rainfall amounts and timing) or even at least on the basis of the balance sheets of past rainfall seasons or years. Therefore, peasant farmers rely on natural environment indicators to forecast the changing seasons, the beginning and end of rainfall spells, or the occurrence of long intermittent dry spells. At the forefront of these indicators is the structure of termite mounds; indeed, the pace of construction of termite mounds reflects the activity of meso-fauna and indicates the beginning of the rainy season as well as the level of humidity of the soil; on the other hand, when termite structures from rainy seasons are established during a dry season, this is taken as an announcement of an early return of rain. Similarly, the nesting period, and seasonal movements of some animal species are traditional indicators of seasonal climate prediction. Thus, peasant farmers in Bantoum emphasize the importance of the behaviour of certain birds in their traditional weather forecasting. This is the case of the mesh Dove (*Spilopelia senegalensis*) and the Jacobin cuckoo (*Clamator jacobinus*) whose seasonal movements are linked to rainfall. If the first nest after the rains is in the early part of the dry season, the Jacobin cuckoo views his nest as occurring during the rainy season. The arrival or departure of these birds in the region announces the end or the beginning of the early rains or not.

In short, the traditional weather forecasting here is mainly based on the elements of nature (flora and fauna); as suggested by the peasants, "animals have a leg up on man in the understanding of natural phenomena" (translation). These phenomena are interpreted to allow the peasants to act in a proactive or reactive manner.

13.6.2 The Modification of the Agricultural Calendar of Corn Growers in Bantoum

Over the years, small corn growers have adapted to climate change by changing their agricultural calendar. Until the late 1990s, corn was grown primarily in the early part of the rainy season, generally from April to July. Soil preparation was undertaken in February and March and overall during the long dry season and harvesting was undertaken during the short dry season from July to early August. Marginally, some farmers cultivating small plots of corn planted some corn plants in a scattered manner in the fields or coffee plantations between August and

October. Because of the lack of rainfall during the short dry season together with false starts and interruptions in the rainy season by long dry spells as described above, corn growers have gradually abandoned the strategy of using the minor rainy season in favour of that of the long rainy season.

As shown in Table 13.5, the short rainy season has experienced since the early 2000s very little enthusiasm, with production in this period being reserved primarily for self-consumption. On the other hand, all respondents grow corn during the long rainy season. The soil is prepared during the short dry season in July and the crop is sown in August. The rain that is concentrated in August, September and October then enables strong plant growth. Harvesting is done without pressure nor fear of rain during the long dry season from November onwards. The production during this campaign, the most important one, is mainly intended for sale. During the dry season, 15 % of farmers use corn in the swamps and bottomlands usually in association with vegetable crops such as tomato, pepper and cabbage. The use of irrigation from rivers, wells and ponds is then organized systematically. In short, to Bantoum, corn cultivation has increased from one campaign each year to three per year (Fig. 13.12).

13.6.3 Specific Measures to Adapt to Dry Spells and Drought

Faced with drought, peasant farmers mainly develop adaptation strategies related mostly to the management of inputs, improved farming techniques and the adoption of alternative measures or measures of socio-economic support.

Table 13.6 clearly shows that droughts are unprepared for by most farmers who have only developed relatively poor adaptive practices related to spatial planning on the farm. Specifically, only 6 % of peasant farmers in the corn sector have developed irrigation systems based on gravity or have built small-scale dams. Several peasant farmers provided an explanation in terms of a lack of financial and technical resources to support their lack of preparedness. However they are more active in the management of production factors.

In order to cope with dry spells, more than half of the peasant farmers carry out a staggered planting process. This practice of spreading the seedlings over time and to leave increments in space reduces the loss of seed capital and ensures that the production is not uniformly affected by the hazard, and some plots take advantage of more clement rainfall conditions. In addition to this practice, 35 to 40 % of the

Table 13.5 Timing of corn cropping by peasants in 2011

Campaign of corn	First campaign (April–July)	Second campaign (August–November)	Third campaign (December–March)
% of growers concerned (in %)	56 %	100 %	15 %

Source: Field interviews

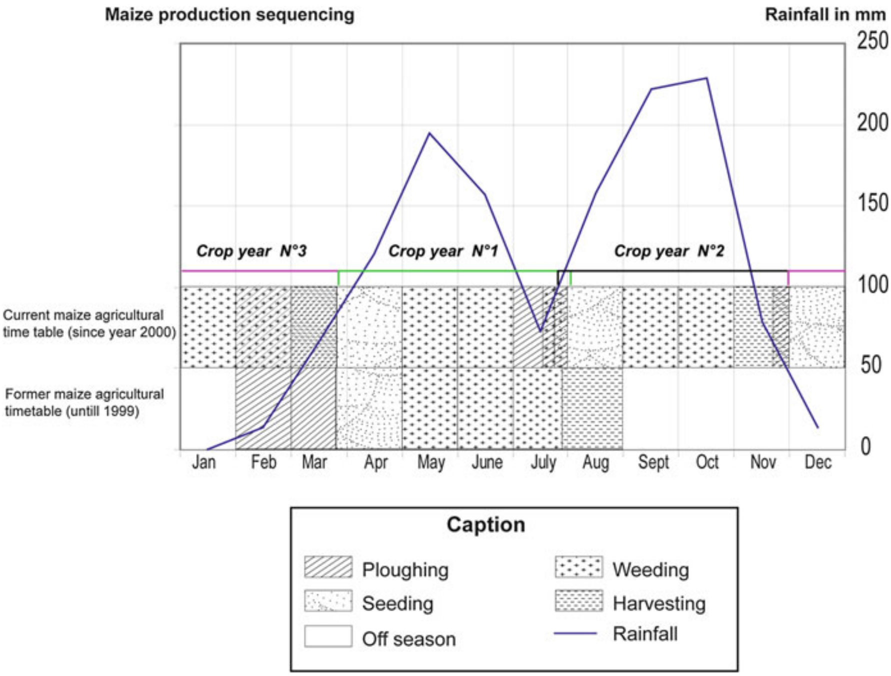


Fig. 13.12 Evolution of the agricultural calendar (Source: Field interviews and DAADER 2010)

Table 13.6 Adaptations relating to infrastructure and spatial planning

	Construction of infrastructure for water collection		Digging wells		Installation of irrigation system		Construction of mini-dams	
	Number of peasants	%	Number of peasants	%	Number of peasants	%	Number of peasants	%
PNR I	7	7.95 %	11	14.77 %	4	5.68 %	2	4.54 %
PNR II			2		1		2	

Source: Field interviews

peasant farmers also use drought resistant crop varieties or improved varieties with a short cycle (3 months) and which are therefore less vulnerable. These are hybrids and especially composites that are resistant to severe dehydration. Hybrid species like Pannar (12, 36, 53), the *Komsoya* and *Bondopa* have the advantage of high yields (4–8 t/ha) but their price is high (2300 F per Kg) and the peasant farmers must pay for new seeds every year. This is why most peasant farmers in Bantoum prefer composite varieties like the *Kassai* (*Composite Highland corn* 101), *Shaba* or *CMS 8704* which are sold at 400 F per Kg and whose crops can be used for seeds for 2–3 years. In addition, these composite varieties have the advantage of being more resistant to climatic stress; their yield is from 1.5 to 4 T/ha. This is much better than the local varieties (the *Ngefed la'*) whose returns are barely 1 T/ha and whose cycle is slightly longer (4 months at least).

Improved farming techniques allows Bantoum farmers to reduce water requirements and losses for their crops. These techniques often lead to a reduction in evapotranspiration. This is due to the construction of windbreaks by hedges, hoeing which reduces evapotranspiration by breaking the continuity between the topsoil and the rest of the ground. For peasant farmers "hoeing is worth two waterings". Weeding reduces water loss and also saves soil nutrients. The combination of cultures creates a favorable microclimate and causes a reduction in water needs.

The dry spells are the most disruptive hazard of peasant agriculture; it obliges 22 % of the peasant farmers to migrate to the shallows to reduce their exposition vis-à-vis rainwater dependence. Moreover, the practice of composting increases fertility and moisture. Crops grown on enriched compost plots are more productive and resistant to climatic stress. The same effect is often obtained through foliar fertilizer (or organic fertilizer).

On Fig. 13.13, the left-hand photo shows a non-fertilized corn field that experienced wilting after a dry spell leading to a slowdown in plant growth. In contrast, the right-hand photo shows a field enriched with compost and foliar fertilizers, which under the same climatic conditions had a satisfactory vegetative growth and production.

In addition, agroforestry practices that were observed for 30 % of the peasant farmers consist of planting fruit trees (safoutiers, avocado, cola), fertilizers species (*Jatropha cajanus*) medicinal species (*moringa Monodora*, *prunus africana*) on the farms. These protect crops and create a shading effect thus reducing the water requirements of plants. In relation to this, one peasant farmer told us: "*These trees contribute to improving the microclimate, soil fertility, well-being, and protection against erosion.*" (translation)

Other measures of adaptation or accompanying measures of a socio-economic nature are also significant in the area.

Fig. 13.13 Comparison of two neighboring corn fields after severe dry spells

Table 13.7 shows that almost all farmers diversify income generating activities (livestock, crafts, fishing, small businesses, non-timber forest products) to reduce their dependence vis-à-vis corn and decrease their vulnerability to rainfall fluctuations. In this sense, access to credit can help develop these activities or improve production conditions. The training mainly concerns reinforcing peasants' technical capacity, managerial capacity and organizational capacity. It involves the work of regional and local authorities, NGOs and DAADER.

13.6.4 Adaptation Measures to Deal with Heavy and Violent Rainfall

To limit the adverse effects of heavy rainfall on agriculture, peasant farmers in Bantoum have developed a number of adaptation strategies.

Based on Table 13.8, it is evident that to reduce crop losses due to excessive rainfall, 60.23 % of the peasant farmers have built barns and cribs for cereals. Other techniques are used in an accessory manner: phytosanitary treatment and bagging or sun drying. Lack of financial means leads the peasant farmers to build cribs in the traditional way by following certain standards for ventilation. During the third season of corn production, peasant farmers use the "*Maya*" technique of breaking the stalk and guiding the ear to the ground to delay the harvest and allow some pre-drying.

Table 13.7 Measures of socio-economic adaptation or accompaniment

	Facilitation of access to credit		Diversification of income sources		Training of peasants in techniques of adaptation	
	Number of peasants	%	Number of peasants	%	Number of peasants	%
PNR I	33	44.31 %	57	84.09 %	26	35.23 %
PNR II	6		17		5	

Source: Field interviews

Table 13.8 Adaptations relating to infrastructure and spatial planning

	Improvement in drainage system		Construction of lofts and cribs for produce conservation		Installation of anti-erosive structures	
	Number of peasants	%	Number of peasants	%	Number of peasants	%
PNR I	2	4.54 %	34	60.23 %	29	42.05 %
PNR II	2		19		8	

Source: Field interviews

Table 13.9 Use of tillage techniques by the surveyed peasant farmers

	Direction of improvements		
	Slope direction	Direction opposite to slope	Direction opposite to water flow
	Number of peasants	Number of peasants	Number of peasants
Ridges	3	52	11
Stepped contours		3	9
Ridges and mounds		10	

Source: Field interviews

Over 80 % of farmers practice ridge tillage in the opposite direction to the slope. Although difficult to achieve, this shows willingness to fight against erosion and loss of soil minerals. The ridges and mounds are more common in the lowlands because they limit impact of floods on crops (Table 13.9). There are also other useful efforts underway to limit plowing. One interviewee peasant said about this: "*An alternative to plowing is to work carefully using a well controlled vegetal cover. This not only limits erosion, but also creates a better water supply for crops, and increases fertility as well as a natural control of weeds*." (translation)

Most farmers in Bantoum use perennial plants as erosion control measures. Their use helps to keep the efforts functional as long as possible by preventing the erosion of the soil and the spread of wildfires. The most used plants are perennial grasses (*vetiver, trypsacum, andropagon gayanus*) to secure the earthworks and stone (stone boundaries, dikes) which are resistant to drought and trampling. To deal with the effects of heavy rains, peasants have been building shelters of bushes or hedges to counteract the wind.

13.6.5 Adaptation Practices in Relation to False starts and the Late Return of Rainfall

False rain starts just as dry spells are recurrent in the area. To address these situations the farmers resort to time-space staggered planting to adjust the planting dates or the agricultural calendar as explained above. These practices are used by almost 69 % of the farmers. The adoption of short cycle varieties that are resistant to drought by 21 % of the peasants, migrations and the development of lowlands allow farmers to reduce their vulnerability to the vagaries of rainfall.

13.6.6 The Support of the State and NGOs for the Adaptation of Corn Farmers to Climate Variability and Change

MINADER[6] and other government and non-government organizations and programs support farmers' strategies to adapt their farming to climate variability and change. Take for example PNVRA[7] for agricultural extension, FIDA,[8] PNDP,[9] APADER,[10] SAILD and the municipality of Bangangté for material and financial support or, capacity building initiatives for peasant farmers in corn production, sustainable land management and the development of micro-scale community projects. The support program for the corn sector initiated by the government specifically provides subsidies to farmers who have developed reliable micro projects. It also provides improved seeds and trains seed growers. Ten or more farmers in the Bantoum area say they have benefited from the contributions of this program. Similarly, material in support of the PNVRA program has also been able to equip various peasant farmer organizations in pumping equipment and to showcase 7 acres of corn crops in 2010 in Bantoum (DAADER 2010). Finally, we note the Reform Programme Fertilizer Sub Sector (PRSSE) that provides peasant farmers the technical forms regarding cultivation practices and informs them about innovation in terms of agricultural inputs.

13.7 Conclusion

Our research highlights a strong inter-annual and seasonal variability of rainfall volumes. To this, is added a clear trend of declining days of rain, a high recurrence of false starts or late starts to the rainy season, excess and high frequency of rainfall in August and September, all things detrimental to the proper development of corn whose cultivation in Bantoum by small peasant farmers depends mainly on what rainfall brings with it. These conditions result in a disruption of the agricultural calendar and the vegetative plant cycle, as well as the degradation of other factors of production. Faced with these impacts, small Bantoum corn growers have adapted, aided by government agencies and non-governmental organizations. They have

[6] *Ministère de l'Agriculture et du Développement Rural* (Ministry of Agriculture and Rural Development).

[7] *Programme National de Vulgarisation de la Recherche Agronomique* (National Programme for Communication of Agronomic Research).

[8] *Fond d'Investissement pour le développement en Afrique* (Investment Fund for Development in Africa).

[9] *Programme National de Développement Participatif* (National Programme of Participative Development).

[10] *Association pour la Promotion des Acteurs de Développement Endogène Rurales* (Association for the Promotion of Actors for Endogenous Rural Development).

modified their agricultural calendar by gradually abandoning the minor rainy season for cultivation in favor of a new production campaign, that of the long rainy season. Moreover, they have set up a campaign during the long dry season in the swamps by using irrigation. Furthermore, they resort also to composite and hybrid varieties with short cycles and high yields and production techniques such as the use of compost and organic foliar fertilizer. The yields for the new rainy season campaign are so good that production has increased enormously over the last decade making Bantoum a large production area that attracts buyers from the cities of Cameroon, Gabon and Equatorial Guinea. Corn producers in groups based on shared initiatives have emerged in the area; these groups serve as forums for sharing experiences and promoting local climate knowledge that has developed over the years as well as good adaptation practices of family farming faced with the constraints of climate change.

References

Batha, R. A. S. (2011). Analyse de l'impact des conditions climatiques sur la production du maïs dans deux agro systèmes à pluviométrie monomodale : Étude comparative entre les départements de la Bénoué et du Wouri au Cameroun. Masters thesis, Université de Yaoundé I (U.Y.I).

C.I.A.T. (2008). *Concepts, cadre méthodologique pour évaluer la vulnérabilité et les stratégies d'adaptation*, Module 2, Rapport du manuel WINOGRAD, Colombie, 32p.

DAADER. (2010). *Rapports annuels de la délégation d'Arrondissement de l'agriculture de Bangangté*, 42p.

De Perthuis et al. (2010). *Rapport sur les économies des adaptations aux changements climatiques*, C.E.D.D, ministère de l'écologie, de l'énergie, du développement durable et de la mer, 90p.

Feumba, R. (2001). *Variabilité pluviométrique saisonnière et comportement des cultivateurs de Tomates à BANTOUM*. Masters thesis, Geography UYI, 134p.

Feumba, R. A., et Tsalefac. (2006). « Variabilité pluviométrique saisonnière, et stratégies des cultivateurs de tomates à BANTOUM ». *Annales de la FALSH de l'université de Ngaoundéré*, *VIII*(Special Issue – Geography), 266–285.

GIEC. (2007). *Rapport d'évaluation sur les impacts, les adaptations et les vulnérabilités*, Annexe I, Cambridge University Press, Cambridge, U.K, 976p.

Kemche, J. (1991). *Crises climatiques récentes et réactions des politiques nationales dans le domaine de l'agriculture : cas du Cameroun*. Masters thesis in Geographye, U.Y.I, 84p.

Kouam, J. B. (2002). *Le projet « route du NOUN » dynamique des villages pionniers et mise en valeur des nouvelles terres agricoles sur la rive droite du NOUN*. Masters thesiss Geography, UDS, 119p.

Kouam, J. B. (2006). Le renouveau agricole dans le département du Ndé : projet de thèse, état des lieux et facteurs. DEA thesis in Geography, Université de Dschang, 93 p

Mbangue, B. S. S. (2009). Adaptabilité et comparaison de quelques cultivars de maïs (zea maïs) en zone de basse et moyenne altitude au Cameroun; mémoire d'ingénieur agronome de la Faculté d'Agronomie et des Sciences Agricoles de l'Université de Dcshang.

Mbaye, D. (1996). « A propos de la durée de la saison de pluies au Sénégal ». *Sècheresse*, *18*(2), 247–266.

Nganso, E. (1982). *La léthargie du département du Ndé, une anomalie dans le dynamisme du pays Bamiléké*. DES thesis, Université de Yaoundé, 168p.

Ozer, P., et Erpicum, M. (1995) « Méthodologie pour une meilleure représentation spatio-temporelle des fluctuations pluviométriques observées au Niger depuis 1905 ». *Sècheresse, 6* (1), 103–108.

Suchel, J. B. (1988). *Les climats au Cameroun*. Doctoral thesis, Université de Bordeaux 3, 168p.

Tsalefac, M. (1999). *Variabilité climatique, crise économique et dynamique des milieux agraires sur les hauts plateaux de l'Ouest Cameroun*. Doctoral thesis es lettres, UYI 564p.

Tuekam, T. C. (2012). Variabilité pluviométrique et adaptations de l'agriculture paysanne au projet « route du Noun » (Arrondissement de Bangangte) 1980–2010.

UNDP. (2005). *Adaptation policy framework for climate change*. UNDP Technical Report, Cambridge University Press, 349p.

Van Vyve. (2006). *Caractérisation de la variabilité spatio-temporelle de la pluies au Niger*. Dossier d'Habilitation à Diriger les Recherches (HDR) in agronomy, Université Catholique de Louvain La Neuve, Presse Universitaire de France, 412p

Feumba Rodrigue Aimé is currently completing his PhD in adaptation to climate change at the University of Ngaoundéré (Cameroon). He is Assistant Lecturer at the Higher Teacher's Training College, The University of Yaounde I. His areas of research encompass adaptation to climate change, climate smart agriculture, sustainability, disaster risk reduction and the management of natural resources. As an expert in climate change, he has contributed to the elaboration of the National Adaptation Plan to climate change of Cameroon and to the process of mainstreaming adaptation to climate change into the agricultural policy of Togo. He is also the cordinator of a local NGO on climate change in Cameroon.

H. Blaise Nguendo-Yongsi completed his PhD in Health Geography at the Université Paris X (France) in 2005. He is currently working with the Institute for Training and Research in Population Studies (University of Yaoundé II, Cameroon). His areas of research cover environmental change, the health of vulnerable populations, and non-communicable diseases.

Christopher R. Bryant received his doctorate in 1970 at the London School of Economics and Political Science (LSE), London. He was progressively Assistant, Associate and Full Professor in Geography at the University of Waterloo (1970 to 1990), then Full Professor in Geography the Université de Montréal (1990 to 2014), and is now Adjunct Profesor in Geography at the University of Montréal and also in the School of Environmental Design and Rural Planning, University of Guelph. He is one of the international leaders in research on urban/periurban agricultures (Canada, Western Europe and elsewhere), and he is also a recognized leader in the domain of adaptation of human activities (and especially agriculture) to climate change and variability, in local and community development, and in the strategic planning for local and regional development for and by citizens.

Chétima Boukar is currently completing his PhD in climate change and food security at the University of Yaoundé I Cameroon. He is working as the climate change expert at the Lake Chad Programm (GIZ/CBLT) in N'Djamena, Chad. His areas of research cover vulnerability to climate change, climate variability, demography, climate smart agriculture and food security.

Cyrille Tuekam Tueche has completed his diploma of secondary school teacher in Geography at the Higher Teacher Training College, University of Yaoundé I in 2012. He is currently completing his Master degree in Geography at the University of Yaoundé I and is working as a secondary school teacher of geography in Yaoundé Cameroon. His areas of research cover environmental education, climatology and adaptation of small farmers to climate change and variability.

Chapter 14
Conclusion

Christopher R. Bryant, Liette Vasseur, Ali Bellichi, Omer Chouinard, Mamadou Adama Sarr, Kénel Délusca, and Christophe-Toussaint Soulard

Abstract Obviously, adapting agriculture to Climate Change and Variability (CCV) requires that the phenomenon is accepted as a reality which is increasingly the case in many countries and territories. But to understand the adoption of adaptation strategies by farmers it is necessary also to appreciate that farmers have to contend with other multiple stressors which they may consider to be more important to tackle in the short to medium term. Any governments which attempt to develop programs to encourage agricultural adaptation to CCV must recognize this and also understand that different socio-economic systems of agricultural

C.R. Bryant (✉)
University of Montréal, Montréal, QC, Canada

School of Environmental Design and Rural Planning, University of Guelph, Guelph, ON, Canada
e-mail: christopher.robin.bryant@gmail.com

L. Vasseur
Department of Biological Sciences, Brock University, St. Catharines, ON, Canada
e-mail: lvasseur@brocku.ca

A. Bellichi
University of Mohamed V, Rabat, Morocco
e-mail: a.bellichi@flsh.um5a.ac.ma

O. Chouinard
Department of Sociology and Environmental Studies, University of Moncton, 18 Ave Antonine-Maillet, B-007 Rémi-Rossignol, Moncton E1A3E9, NB, Canada
e-mail: omer.chouinard@umoncton.ca

M.A. Sarr
Université de Montréal (Québec, Canada) and Centre de Suivi Écologique (Dakar, Senegal), Dakar, Senegal
e-mail: mamadou_sarr74@hotmail.com; adama.sarr@cse.sn

K. Délusca
Institut des Technologies et des Études Avancées d'Haïti (ISTEAH), Port-au-Prince, Cap-Haïtien, Hinche, Haiti
e-mail: kenel.delusca@gmail.com

C.-T. Soulard
French Institute for Agricultural Research (INRA), Montpellier, France
e-mail: soulard@supagro.inra.fr

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4_14

production are frequently associated with different pressures and capacities to adapt to CCV and other stressors. Understanding how farmers react also means that we must understand the importance of integrating local and traditional knowledge concerning economic, social and eco-systemic issues in evaluating adaptation options in particular countries and their agricultural territories. Adaptation to CCV should also be regarded as an innovation diffusion process, meaning that it is critical to understand social networks and the multiple factors that influence the acceptability of different adaptation strategies in different communities and territories.

In this Conclusion, it is strongly suggested that the action research approach is a very constructive approach in helping farmers and other actors increase their capacity to develop appropriate adaptation strategies in their communities and territories. At the same time, this provides an important opportunity to integrate traditional farmer knowledge into the development of appropriate government programs and policies. It is also suggested that appropriate and effective research needs to be interdisciplinary. Finally, it is suggested that developing appropriate and effective adaptation strategies to deal with CCV must also recognize the multiple other functions that agricultural activities and land provide for society since this is also a way of building more general support for maintaining agricultural activities.

Keywords The reality of CCV • Local and traditional knowledge • Adaptation as a diffusion process • Multiple stressors facing agriculture

This book has focused on the adaptation of agriculture and its various activities to Climate Change and Variability. It has not dealt with the issue of mitigation or the reduction of greenhouse gas emissions which is also a major challenge in managing Climate Change and Variability. Mitigation also implies adaptation processes for many actors, including governments, many types of businesses including resource extraction (e.g. coal mining and oil extraction), and citizens and families (e.g. changing the types of individual transport families use). Even if substantial international agreements were to be reached to reduce the emissions of greenhouse gases, the time scale for success would likely still be substantial. This implies that adaptation of many human activities such as agriculture would still be needed. It is in this context that this book was undertaken, i.e. that whatever happens in terms of reducing greenhouse gas emissions, Climate Change and Variability will still be with us for "some time" and adaptation of many activities will continue to be essential. The focus of adaptation in this book has been on agricultural activities which is of major importance to human life on Earth, as food and nutrition security for many countries already faces significant challenges, and these challenges are only likely to get worse as population increases and the capacity of agriculture in many countries to maintain or even increase food production and quality is currently being reduced by climate change and other stressors.

In this context we believe that a number of key messages can be extracted from the research reported on in this book. These messages are based on various experiences which provide or reinforce a number of important messages and communalities. The Conclusion ends with the identification of what we consider to be the principal directions for future research.

14.1 Key Messages Regarding Agricultural Adaptation to Climate Change and Variability

The key messages from the different chapters deal with progress but also continuing challenges in relation to adaptation to Climate Change and Variability.

(a) Climate Change and Variability as a real phenomenon to tackle through adaptation

In relation to Climate Change and Variability, it is interesting to note from the different chapters that a growing number of farming communities in Canada, France, and parts of Africa finally appear to have accepted the reality of Climate Change and Variability. This has occurred quite slowly in many areas, but when farmers have been presented with analyses showing the realities of how farming in their territories have experienced greater variations in agricultural production over time reflecting the increasing occurrence of difficult climate conditions, the farmers became increasingly convinced of the reality of Climate Change and Variability and became interested in how different adaptation strategies could help. In addition, when farmers and other actors in other geographical contexts were brought together in various types of discussion groups, everyone shared their experiences over the recent past which once again convinced them of the reality of this phenomenon. This shows the importance of the integration of farmers and other actors in more of an action research process when the farmers and other actors can have an influence on the research process.

(b) The importance of integrating local and traditional knowledge ranging from economic, social and eco-systemic issues in evaluating adaptation options

Professionals and researchers have much to learn about adaptation to climate change and variability, especially at the local level. The integration of traditional knowledge in projects can help understand what farmers experience and the intricate nature of the farming system. Similarly, integrating climate change scenarios and economic modeling, when assessing different adaptation options, may help improve farmers' understanding and acceptability of these solutions. However, these solutions can also be strengthened if farmers are involved in the process. This demonstrates the importance of linking modeling exercises to field experiences. It can lead to the co-construction of sound and sustainable adaptation strategies, greater adoption of solutions, and potentially better governmental support to facilitate adaptation. This also suggests that such research is following a real action research approach to dealing with many of the practical issues facing agriculture in relation to Climate Change and Variability.

(c) Adaption strategies as a diffusion process and the importance of understanding social networks

Several of the chapters of this book demonstrate that adaptation to Climate Change and Variability can be seen as a process of the diffusion of innovations. The importance some farmers attach to dealing with certain types of actors as sources of information on appropriate adaptation strategies (e.g. private sector companies) showed the difficulties of relying on central state programs of supporting adaptation to Climate Change and Variability. In some countries, extension workers have very limited expertise in regards to climate change adaptation and may believe that one size fits all. However, regional and cultural differences as well as the types of farming may greatly affect what adaptation strategies can be more appropriate. It is therefore important for governments to understand their limits and promote training of their agencies to better cope with these conditions.

(d) It is essential in understanding adaptation to Climate Change and Variability to appreciate that this stressor is not the only source of stress that farmers may face

Even when farmers understand the reality of Climate Change and Variability and the actual and potential impacts on their farms, other stressors may appear more urgent to deal with in the short to medium term. Pragmatism prevails when, for example, a farmer needs to deal with a new pest invasion, when children are uninterested in taking over the farm during illness or when the children do not wish to take over the family farm because they are more attracted to employment opportunities in urban areas, or when farmers have to contend with strong competition from other regions and countries. Farming has become marginalized in many countries and poor farmers are highly vulnerable to social and economic pressures. Their main daily goal is often limited to putting food on their own tables. Questionnaires or focus groups simply oriented to dealing with Climate Change and Variability as the stressor to adapt to can lead to limited understanding on what farmers really have to deal with.

14.2 New Directions for Research on Adaptation of Agriculture

Based on the arguments in some of the chapters and also on our own reflection, a number of new directions for research seem worthwhile presenting and explaining.

1. Action research through processes of co-construction aimed at, for instance, the increase in capacity of farmers (and other actors) to adapt to Climate Change and Variability

Action research is a process that has been pursued in various domains, but only recently in the domain of adaptation to Climate Change and Variability. Action research, involving interacting directly with farmers, government agencies and local and regional governments as well as other professionals (e.g. water management specialists, agronomists . . .), can lead to the co-construction of programs and initiatives aimed at supporting adaptation to Climate Change and Variability. While sometimes funding may be made available to support certain types of adaptation, what appears to be more important is provision of pertinent advice from actors that are appreciated and trusted by farmers. Action research usually involves researchers but other actors can also appropriate the functions of action research (e.g. Bryant and Chahine 2015; Bousbaine and Bryant 2015).

2. A better recognition of the importance of local (farmer) knowledge (including traditional knowledge especially in developing countries as in Africa) and its integration into government programs and policies

   We have already noted in several chapters that it is evident that local knowledge on the part of farmers often provides a reality check on what other actors (many researchers, agronomists, government representatives . . .) may suggest in terms of adaptation strategies. When the other actors include government, it is essential that dealing with agricultural adaptation to Climate Change and Variability necessarily requires dealing directly with farmers and recognizing that they have a great knowledge base which needs to be integrated into the preparation of any program to support adaptation, at any level.

3. A better integration of social-ecological agrosystem and socio-ecological systems generally

   It is clear that by adapting to Climate Change and Variability, the farming community will be able to improve its resilience. However it is important to remember that agricultural lands are part of a larger landscape that connects the social, cultural and ecological structures into something that is quite cohesive. This landscape remains fragile when not all its components, especially biodiversity and ecosystem services, are considered. Further research is needed in analyzing the position of agricultural lands into the social-ecological system at a greater scale and how tools such as co-management may help enhance this integration for adaptation at the larger scale. In terms of adaptation of agriculture to Climate Change and Variability, and given the importance of social-ecological agrosystems and socio-ecological systems more generally, it would be natural for research to tackle also the effects of Climate Change and Variability on the production of eco-services supported by farmland and farming activities and to explore whether the adaptation strategies adopted enhance or undermine the eco-services produced for society.

The experiences of the authors of the different chapters in this book and their interactions with farmers clearly show the importance of pursuing integrated research that can better connect the various actors who are involved directly or indirectly in the sustainability of farmers and their agroecosystems in the face of

Climate Change and Variability. Interdisciplinary teams are an obvious approach to such multi-facetted phenomena as are found in the adaptation of agriculture to Climate Change and Variability and such teams, especially if following an action research process, have the potential to rapidly advance our knowledge and find solutions to adapt to an increasingly growing risk that is Climate Change and Variability.

Thus, given the recognition of the importance of local and traditional knowledge on the part of farmers it is argued that it is imperative that farmers and their families (and workers if there are any) be involved in discussions aimed at developing pertinent adaptation strategies for agriculture. This also strongly suggests that action research be supported and encouraged since it is a major way in which local and traditional knowledge can be integrated into the construction (and especially the co-construction) of pertinent adaptation strategies. Finally, developing adaptation strategies for agricultural activities needs to recognize that farmland and farming activities can provide significant functions to society other than food production. These other functions include eco-services such as ensuring that agricultural pollution is minimized and that effective water supplies and their usage on farms are undertaken taking into consideration the effects of such strategies on the overall ecosystem and other human activities. This suggests very strongly that research into agricultural adaptation strategies should take into account these other services, more generally known as being part of the multiple functions (market and non market based . . . the latter including eco-services) or the multifunctionality of agricultural land and farming activities.

Appropriate assessment of adaptation strategies is a key component of the Adaptation Process. The Adaptation Process is not only time and resources-consuming; it has also to deal with a cascade of uncertainties related to the complex nature of anthropogenic climate change and variability. As farmers, especially those of developing countries, usually evolve in a constraining environment and with limited resources, it becomes fundamental that the adopted adaptation strategies are evaluated rigorously and that the outcomes of these assessments are used for the identification of best practices likely to be reproduced by other farmers or scaled-up in an entire region. Therefore, a strong emphasis needs to be put on techniques, methods and tools in evaluating impacts of adaptations strategies. Needless to say, the latter can heavily rely on the evaluation approaches already in place and tested in other fields; however it remains obvious that they need to take into account the specific characteristics of the adaptation process in the context of climate changing conditions combined with other stressors.

References

Bryant, C. R., & Chahine, G. (2015). Action research and reducing the vulnerability of periurban agriculture: A case study from the Montreal Region. *Geographical Research*, *2015*, 1–11. On-line Wiley and Sons (Special Issue on: Rural Action Research).

Bousbaine, A. D., & Bryant, C. R. (2015). The Integration of action research and traditional field research to provide sustainable solutions to maintaining periurban agriculture. *Geographical Research*, *2015*, 1–11. On-line Wiley and Sons (Special Issue on Rural Action Research).

Christopher R. Bryant received his doctorate in 1970 at the London School of Economics and Political Science (LSE), London. He was progressively Assistant, Associate and Full Professor in Geography at the University of Waterloo (1970 to 1990), then Full Professor in Geography at the University of Montréal (1990 to 2014), and is now Adjunct Professor in Geography at the University of Montréal and also in the School of Environmental Design and Rural Planning, University of Guelph. He is one of the international leaders in research on urban/periurban agricultures (Canada, Western Europe and elsewhere), and he is also a recognized leader in the domain of adaptation of human activities (and especially agriculture) to climate change and variability, in local and community development, and in the strategic planning for local and regional development for and by citizens.

Liette Vasseur has a PhD from Queens University and is a Full Professor in the Department of Biological Sciences at Brock University where she is also a member of the Women and Gender Studies program and the Environmental Sustainability Research Centre. Since 2014, she holds the UNESCO Chair on Community Sustainability: from local to global, at Brock. She currently leads the thematic group on Climate Change Adaptation of the Commission for Ecosystem Management of the International Union for Conservation of Nature. Her research interests are highly interdisciplinary in the areas of community-based ecosystem management, climate change adaptation and resilience and sustainable agriculture.

Ali Bellichi holds a PhD in Climatology from the University of Aix–Marseille II, France, as well as a PhD in Climatology from the University of Liege, Belgium. He is currently a professor at the University of Mohamed V, Rabat. Morocco. His main research interests are Climate variability and global change, Atmospheric circulation, Weather regimes (North Atlantic), Moroccan climate, Enso regulation and Teleconnection.

Omer Chouinard holds a Ph.D. in Sociology (UQAM, 1992). He is professor in the Department of Sociology and Master's Program in Environmental Studies at the University of Moncton. He directed the program from 1999 to 2007. He has worked 40 years in the areas of sustainable development, community involvement, natural resource management, outreach and education, the environment and building community capacity to take care of their environment. His principal current research interests are in the domain of coastal community adaptation to climate change, and he has published widely in this domain.

Mamadou Adama Sarr received his PhD from the Université Jean Moulin Lyon III, France. His current affiliation is as a Researcher with the Centre de Suivi Écologique, Dakar, Senegal. He was also a post-doctoral Fellow in the Laboratory of Sustainable Development and Territorial Dynamics, Geography at the Université de Montréal. His research interests are in climatology, climate change, regional climate modeling, climate variability and extreme, Geographic Information Systems and Socio-Ecological Systems.

Kénel Délusca is an agronomist engineer by training; his PhD is in Physical Geography (University of Montreal) with a specialization in climatology. Dr. Délusca was project coordinator and a postdoctoral fellow at the Laboratory of Sustainable Development and Territorial Dynamics within the Department of Geography (University of Montreal) where he worked on the assessment of the impacts of climate variability and change on agriculture in Quebec and Eastern Ontario and on the co-construction of adaptation policies and programs. Between 2013 and 2015, he was a visiting scholar at the Geography Department of Université de Montréal and Research Engineer at the French National Institute for Agricultural Research (INRA). Dr. Délusca has published several scientific papers and produced several reports related to the assessment of climate change impacts on agriculture and coastal zones with a focus on water issues. He is actually Adjunct Professor at the Institut des Technologies et des Études Avancées d'Haïti (ISTEAH) and Team Leader of the Technical Assistance to an European Climate Change-funded project in Haiti. His research interests are: climate change vulnerability assessment, high-resolution climate scenario elaboration, crop modeling, climate change policy, environmental evaluation, and multi criteria analysis.

Christophe-Toussaint Soulard is a researcher at the INRA centre of Montpellier, France. With a PhD in Geography in 1999, his PhD work focused on the relations between the geography of farmer's practices and water pollution management in France. From 2010 to 2014, he was director of the joint research unit "UMR Innovation" which studies the innovation and development processes in Agriculture and Food. For the last 10 years, he has been head of a multidiscplinary research group which analyses the relations between agriculture and urban development. He managed the international DAUME project focusing on the sustainability of urban agriculture in the Mediterranean. He is also recognized for his work involving action research. In 2015, his team supported the metropolitan council of the City of Montpellier (a population of 450,000) to develop an agricultural and food policy.

Index

C.R. Bryant et al. (eds.), *Agricultural Adaptation to Climate Change*,
DOI 10.1007/978-3-319-31392-4