# Building resilience for adaptation to climate change in the agriculture sector

## Proceedings of a Joint FAO/OECD Workshop

# BUILDING RESILIENCE FOR ADAPTATION TO CLIMATE CHANGE IN THE AGRICULTURE SECTOR

## Proceedings of a Joint FAO/OECD Workshop
## 23–24 April 2012

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# Acknowledgments

The joint FAO/OECD Workshop on Building Resilience for Adaptation to Climate Change in the Agriculture Sector was organized by FAO and OECD, and held on the 23–24 April 2012 at FAO headquarters in Rome, Italy.

We would like to extend our special thanks to all the participants for their contributions and papers. Our appreciation also is expressed to the organizers of this Workshop – Andrew Dale, Jussi Lankoski, Alexandre Meybeck, Nadine Azzu and Vincent Gitz. In addition, we would also like to thank Shivaji Pandey, Caterina Batello, Véronique de Saint Martin, Suzanne Redfern and Elizabeth Pain Innamorati.

# Agenda

## Monday, 23 April 2012

09.30 – 10.00 **Introductory remarks**

**FAO**: Modibo Traoré, Assistant Director-General, Agriculture and Consumer Protection Department

**OECD**: Dale Andrew, Head, Environment Division, Trade and Agriculture Directorate

10.00 – 11.30 **I. Global view**

**Chair**: Dale Andrew

The first introductory session gives a broad overview on the notions of risks, vulnerabilities and resilience and how to consider them in the context of climate change. It addresses the issues of interactions between the various types of risks and vulnerabilities, from biophysical and economic perspectives, including considerations of scale and time, in order to better define resilience, there again from biophysical and economic perspectives and including considerations of scale and time.

- **Agriculture and climate change: overview** (Peter Holmgren, FAO, Director Climate and Energy Division, Natural Resources and Environment Department).
- **Risks, vulnerabilities and resilience in a context of climate change** (Vincent Gitz, FAO, Agriculture and Consumer Protection Department).
- **The assessment of climate change related vulnerability in the agricultural sector: reviewing conceptual frameworks** (Thomas Fellmann, University of Seville, Spain).

11.30 – 12.30
and
14.00 – 15.00 **II. Types of risks and of risk management**

**Chair**: Berhe Tekola

The second session considers various biophysical risks affecting production, economic risks, both for producers and small holders as consumers, the impact climate change may have on them and the ways to address these various risks.

- **Animal diseases: more disease...old and new** (Juan Lubroth, FAO, Agriculture and Consumer Protection Department).
- **Climatic risks: assessment and management in agriculture** (Selvaraju Ramasamy, FAO, Natural Resources and Environment Department).

**Chair**: Aseffa Abreha

- **Coping with changes in cropping systems: plant pests and seeds** (Manuela Allara, FAO, Agriculture and Consumer Protection Department).
- **Building resilience for adaptation to climate change in the fisheries and aquaculture sector** (Cassandra De Young, FAO, Fisheries and Aquaculture Department).
- **Building resilience to climate change through sustainable forest management** (Susan Braatz, FAO, Forestry Department).

15.00 – 17.00 **Chair**: Bob MacGregor

- **Farm risk management policies under climate change** (Jesús Antón, OECD/TAD).
- **The assessment of the socio-economic impacts of climate change at household level** (Panagiotis Karfakis, FAO, Economic and Social Development Department).
- **The urgency to support resilient livelihoods: FAO disaster risk reduction for food and nutrition security framework programme** (Cristina Amaral, FAO, Technical Cooperation Department).
- **Agriculture in National Adaptation Programmes of Action** (NAPA) (Alexandre Meybeck, FAO, Agriculture and Consumer Protection Department).
- **The International Treaty for Plant Genetic Resources in Food and Agriculture** (Shakeel Bhatti, Secretary, International Treaty on Plant Genetic Resources for Food and Agriculture).

17.30 – 18.30 Welcome reception hosted by FAO

## Tuesday, 24 April 2012

9.30 – 10.30 **III. Case studies (Part 1)**

**Chair**: Guido Bonati

The third session is devoted to case studies, which have been selected to cover a broad set of issues, farming systems and social and economic situations. For each, specific risks and vulnerabilities are analysed, the way they are expected to be influenced by climate change and how resilience can be improved to adapt to climate change.

- **Crop production in a northern climate** (Helena Kahiluoto, MTT Agrifood Research, Finland).
- **A broad overview of the main problems derived from climate change that will affect agricultural production in the Mediterranean area** (Demetrios Psaltopoulos and Dimitrios Skuras, University of Patras, Greece).

10.30 – 11.30 **III. Case studies (Part 2)**

**Chair**: S.K. Pattanayak

- **Crop-livestock production systems in the Sahel: increasing resilience for adaptation to climate change and preserving food security** (Alexandre Ickowicz, CIRAD).
- **Rice systems in Southeast Asia: challenges to production** (Caterina Batello, FAO, Agriculture and Consumer Protection Department).

11.30 – 12.30 **IV. Tools, policies, institutions**

**Chair**: Marca Weinberg

These sessions focus on tools, policies and institutions designed to monitor and manage risks and vulnerabilities and how they can be enhanced and modified to better help agriculture adapt to Climate Change.

14.00 – 15.30 **Country presentations:**

- **Italian presentation on "Perspectives on risk management in agriculture in Italy"** (Antonella Pontrandolfi, INEA, Italy).
- **Canadian presentation on "The resiliency of the Canadian crop insurance system under climate change: testing quantitative methods"** (Bob MacGregor, Agriculture and Agri-food Canada, Canada).
- **Spanish presentation on "Exploring adaptation to climate change in Spain (looking into the future without a crystal ball)"** (Ana Iglesias, Universidad Politecnica de Madrid, Spain).
- **Dutch presentation on "Towards climate resilient agriculture: the Dutch touch"** (Sjoerd Croqué).

**Chair**: Chang-Gil Kim

**Country presentations continued:**

- **EU presentation on "The EU agricultural policy: delivering on adaptation to climate change"** (Maria Fuentes, EC).
- **Swiss presentation on "Swiss climate strategy for agriculture"** (Daniel Felder, Federal Department of Economic Affairs FDEA, Switzerland).
- **Japanese presentation on "Japanese adaptation policy and AMICAF (Analysis and Mapping of Impacts under Climate change for Adaptation and Food security) project"** (Hiroki Sasaki, Ministry of Agriculture, Forestry and Fisheries, Japan).
- **Australian presentation on "Australia's Carbon Farming Initiative (CFI)"** (Eliza Murray, Director, Department of Climate Change and Energy Efficiency, Australia).
- **United States of America presentation on "Agricultural response to a changing climate: the role of economics and policy in the United States"** (Marca Weinberg, USDA).

15.30 – 16.30 **Summary remarks from session chairs and open discussion**

16.30 – 17.00 **Concluding remarks** (FAO/OECD)

# Summary report and main conclusions

The joint workshop on *Building resilience for adaptation to climate change in the agriculture sector* was organized by FAO and OECD, and was held from 23 to 24 April 2012, at FAO headquarters in Rome.

## BACKGROUND AND OBJECTIVES OF THE WORKSHOP

This workshop was a follow-up of the Joint OECD-INEA-FAO Workshop on *Agriculture and Adaptation to Climate Change*, which was held in June 2010. One of the conclusions of that 2010 Workshop was that, as climate change brings new uncertainties, adds new risks and changes already existing risks, one of the most effective ways for agriculture to adapt to climate change could be to increase its resilience. This is why this workshop started from the various types of risks to which agriculture is prone, considered the impact that climate change is expected to have on them, and discussed various risk management strategies, depending on types of risks, and the country and region in question.

This two-day workshop consisted of four sessions including setting the scene, types of risks and risk management, case studies and, finally, tools, policies and institutions.

## FIRST SESSION: SETTING THE SCENE

The first introductory session presented an overview of the main issues in agriculture and climate change, provided definitions of risks, vulnerabilities, resilience and adaptive capacity, and reviewed conceptual frameworks for climate change-related vulnerability. The presentations stressed that there are two main long-term goals for agriculture: (i) achieve food security; and (ii) adapt to climate change. Climate smart agriculture addresses multiple goals, such as the sustainable increase of productivity, increased resilience and reduction of sector's GHG emissions, whereas the FAO-wide framework "FAO-Adapt" aims to mainstream climate change adaptation into all FAO development activities. It was noted that it is important to build resilience to existing risks and to changes in an evolving context. Alternative concepts of vulnerability were reviewed, including outcome and contextual vulnerability of which the former is based mainly on natural science and the latter on social science. A framework table for the practical assessment of climate changed-related vulnerability was also presented.

## SECOND SESSION: TYPES OF RISKS AND OF RISK MANAGEMENT

The second session considered various biophysical and economic risks affecting crop and livestock production, fisheries and aquaculture, forests and agroforestry, as well as households. It also considered risk management strategies to address these risks and how they are adapted to changing conditions. It also briefly reviewed national adaptation plans for least developed countries (LDCs) as related to agriculture.

The presentations stressed the fact that various biophysical risks (weather, animal diseases, plant pests) are going to change – in terms of their nature, frequency and location – and in many cases in an uncertain way. This makes the need for tools and means to monitor risks even more necessary. The presentations also emphasized the fact that it is difficult to predict the impacts of climate change on ecosystems as each component of the system will react differently, and hence changing relationships within the system. This is of crucial importance for forestry and fisheries, but also for agro-ecosystems. Moreover, it was stressed that building resilience to climate change starts by building resilience through sustainable management of natural resources and ecosystem restoration. Interventions on both plant pests and animal diseases emphasized the importance of early action to prevent the spread of the risk. This requires having the proper tools, policies and institutions in place. A typical example is seeds – an essential tool for farmers to adapt to change. It requires preserving genetic resources and then making them accessible: multiplying and diffusing them where they are needed. As regards farm risk management policies such as different types of insurance and *ex-post* payments, it was shown that the possibility of extreme climatic events significantly changes the decision environment and that government's best response to this ambiguity is the implementation of "robust" policies, which may not be optimal under any given scenario, but which allow avoiding negative outcomes.

## THIRD SESSION: CASE STUDIES

The third session was devoted to case studies, which had been selected to cover a broad range of issues, farming systems and social and economic situations. For each case study, specific risks and vulnerabilities were analysed, and looked at the way they are expected to be influenced by climate change and how resilience can be improved to adapt to climate change.

The Finnish case study on crop production in a northern climate addressed the issue whether diversity enhances resilience and adaptive capacity and whether there is a trade-off between diversity and efficiency. It was found that there is no trade-off in land use diversity and resource use efficiency – and in fact there are even cases of positive correlation between diversity and efficiency. The Mediterranean case study gave a broad overview of the main impacts of climate change in the area. It was noted that the Mediterranean is a climate-change hotspot area, and building a resilience strategy is a priority "no regret" action. The third case study considered vulnerabilities and conditions for resilience in crop–livestock systems in the Sahel region. The study shows that these systems have to address, in addition to climate change, other important sources of risks, including economic and land tenure risks but also important drivers of change including population growth. The fourth study considered challenges to production in rice systems in Southeast Asia. Importantly, it underlined that population increase in Southeast Asia has not been matched by an equivalent increase in production. It also underlined that the international rice market is very thin (7 percent of production) and that it is dominated by a few countries. This increases importing countries' vulnerability to price volatility.

## FOURTH SESSION: POLICIES, TOOLS AND INSTITUTIONS

The fourth session focused on tools, policies and institutions designed to monitor and manage risks and vulnerabilities in OECD member countries. This was an informative session of concrete policies and institutions that OECD countries have in managing farm risks in a changing climate and introduced several new policies and policy frameworks to address adaptation to climate change.

## MAIN CONCLUSIONS

The various sessions of the workshop questioned the notion of resilience from very different angles, confronting concepts, specific risk management strategies, case studies and national policies, from different perspectives, biophysical, economic, or social and institutional, and at various scales, from farm and household to national and global.

The confrontation of these various approaches and the discussions that followed led to some important points.

- There are huge uncertainties in the way climate change will directly and indirectly impact agricultural and food systems, and related vulnerabilities.
- Building resilience now is central to being prepared for future changes.
- The notion of resilience enables examining together various domains – biophysical (ecosystems), economic, social and institutional – and scales of operation.
- It also allows the interactions between domains and between scales to be analysed.

The workshop also identified some general ways to increase resilience:

- Identify and monitor potential risks and vulnerabilities. Early action is needed, especially to avoid cumulative and long-term effects.
- Increase the adaptive capacity of farmers and systems, both to recover from shocks and to be prepared for changes.
- Take into account interactions between domains and scales in order to reduce the transmission of shocks between them.

# Opening remarks

*Modibo Traore’*
*Assistant Director-General, Agriculture and Consumer Protection Department, FAO, Rome*

Your Excellencies, Ambassadors and Permanent Representatives, OECD Delegates, Members of the Advisory Group to the Bureau of CFS, distinguished Participants, Ladies and Gentlemen.

It is my great pleasure and honour to welcome you to this FAO/OECD workshop on Building Resilience for Adaptation to Climate Change in the Agriculture Sector.

The collaboration between FAO and OECD is old and rich. The OECD-FAO Agricultural Outlook is probably the best known example of this, but there are many other fields in which we work together.

The Joint Working Party of OECD on Agriculture and Environment has been a pioneer in linking agriculture and environment from an economic and policy perspective. The work of your group on agro-environmental indicators has exerted a tremendous influence on the design of such indicators, worldwide.

More recently, the work of your group has been essential in the global reflection about green economy and agriculture. What does green economy mean for agriculture? What is agriculture’s contribution to green economy, to green growth?

I would like to take this opportunity to thank you for these contributions to our common understanding of the complex interactions among agriculture, environment and economics for improving policy design.

Your group and my Department work on the same issues, from different but complementary perspectives. That is why, since your first invitation to us in 2007 to participate as an observer to the work of your group, the collaboration has been extremely fruitful. This workshop is a good example of it.

Agricultural systems – food systems – are complex. They are biophysical systems, economic systems, social systems. And these dimensions interact with each other, at various scales, from local to global and, again, from global to local.

This is why, to consider adaptation of agricultural and food systems, we need to adopt a holistic approach, from different angles and different perspectives. Here again, it is not only about ensuring a “balanced” view. It is to take into account, at the same time, diverse perspectives and approaches. To consider very technical issues: animal health, plant pests; and also economic perspectives, and households, and policies. Because all of these make up the food system. All of these, and their interactions, are going to be modified by climate change.

In June 2010, we had a first joint workshop, hosted by the Istituto Nazionale di Economia Agraria, on Agriculture and adaptation to climate change.

Climate change brings new uncertainties, and adds new risks and changes to already existing risks. One of the conclusions of the workshop was to consider how building resilience in agriculture could be a way to adapt to climate change. This workshop builds upon these conclusions.

Building resilience is not specific to climate change; climate change adaptation responses are "embedded" in agricultural systems (therefore, sometime there is a difficulty to distinguish adaptation practices *stricto-sensu*). How do we need to increase resilience and build adaptive capacity? We need to adopt a holistic approach, embracing various risks, and accounting for synergies and trade-offs. There are huge variations between countries, in terms of risks to be faced and capacities to face them.

The workshop will consider various types of risks to which agriculture is prone, the effects that climate change is expected to have on them, and various risk management strategies, depending on types of risks and the country in question. It will examine technical issues and case studies in order to determine how addressing various types of risks and vulnerabilities, including plant pests and diseases, animal health and socio-economic vulnerabilities, can contribute to prepare agriculture for future climate-induced risks and uncertainties.

In the international negotiations on climate change, in the United Nations Framework Convention on Climate Change, there is now a much stronger interest for adaptation: the Cancun Agreement contains a framework for adaptation, including a programme of work on loss and damages and the establishment of national plans of adaptation for developing countries.

The Committee on World Food Security (CFS) has requested its High Level Panel of Experts (HLPE) to undertake a study on climate change and food security, which will be presented to CFS in October 2012.

During the UNFCCC meeting in Bonn in May this year, there was a dialogue on agriculture and climate change, which could lead to a decision in Doha on a programme of work.

For all these reasons, there is now an opportunity to better emphasize the importance and the specificities of the adaptation of agriculture to climate change.

This meeting can make a very timely and useful contribution to these various processes.

I wish you a successful discussion.

Thank you.

# Opening remarks

*Dale Andrew*
*Head, Environment Division, OECD Trade and Agriculture Directorate*

This joint workshop is an undertaking between the OECD Trade and Agriculture Directorate and the FAO and builds on the workshop on *Agriculture and Adaptation to Climate Change,* hosted by INEA and held in June 2010.

In the intervening year and half since our joint workshop in 2010 on agriculture and adaptation to climate change, international discussions on the importance of agriculture in slowing climate change have progressed: risk management tools continue to be developed, climate-smart agriculture has deepened its operational activities in technical agencies and the multilateral development banks, and new national initiatives have emerged. Agriculture is no longer a forgotten sector in climate change discussions and action programmes.

Among the key messages emerging from our joint workhop in 2010 were:

1) ***Impacts are region-specific*****:** As a result we have commissioned three studies for the workshop today on the probable effects of climate change on the Mediterrannean, on the Sahel and in northern climates.
2) ***The need for agriculture to adapt was specific to activity and crops:*** Today we will hear specific presentations on fisheries, forestry, rice, animal diseases and plant pests and seeds.
3) ***Adaptation affects individual farmers, agricultural policies and defining activities in international bodies:*** Relevant here is the OECD presentation on its work on risk management at the farm level. And FAO will explain several of its activities including those on the consumer side. Concerning the most vulnerable economically, *National adaptation programmes of action* or NAPAs will be surveyed. NAPAs provide a process for least developed countries to identify priority activities that respond to their *urgent* and *immediate* needs to adapt to climate change – those for which further delay would increase vulnerability and/or costs at a later stage.

**Finally, what is the appropriate role of government action ?**

In conclusions of the 2010 workshop, government interventions were portrayed on a continuum from that of providing infrastructure, including information, through that of redesigning incentives, for some limiting incentives to the provision of public goods while some possibly considered going further. The workshop came up with a few reference points:

a) *It was too soon for specific targeted measures; maladaptation was a distinct possibility.* But several generic policies were appropriate and should be considered. In this context, areas for building resilience in supporting institutions will be taken up today.
b) *Models can be helpful but are an unsafe basis for adaptation strategies – their results depend on the storyline.*

There is uncertainty about the uncertainties – as our OECD team has discovered and will be explained today in the presentation. Other tools will be touched on.

c) *Therefore it is safe to say that uncertainty reigns on how much will be needed from governments beyond the basic provision of information*

This is an ongoing debate. We will hear in the next two days how eight OECD countries and the European Union are adapting their policies to address challenges of supporting adaptation to climate change in their agriculture sector.

With these general remarks on the context of the ongoing cooperation between OECD and FAO, we will get underway with three presentations on the broad overview of adaptation of agriculture to climate change before moving on to sectoral and geographical aspects of building resilience for adaptation. A warm welcome to all.

# Papers presented

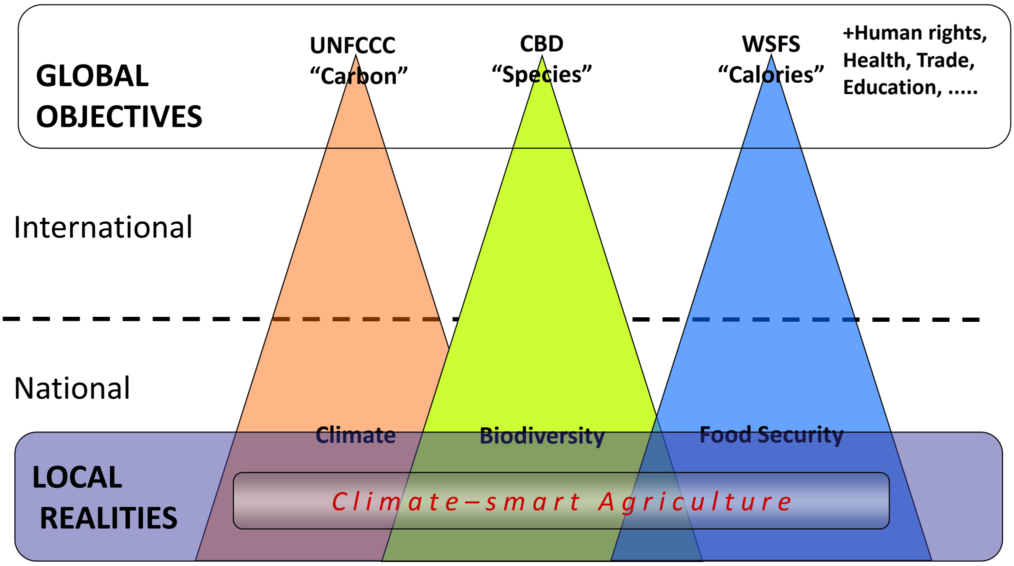
# Agriculture and climate change – overview

*Peter Holmgren*
*Director, Climate and Energy Division, FAO, Rome*

In the wider context, there are two major issues to be faced. First, there is the need to achieve food security to feed the 1 billion hungry. To achieve this, food production needs to be increased by 60 percent by 2050, thus adaptation to climate change is critical. Second, there is the need to avoid dangerous climate change effects – in order to meet the "2 degree goal", major emission cuts are required. As agriculture and land use contribute 30 percent of these emissions, reducing them must be part of the solution.

## CLIMATE-SMART AGRICULTURE

Climate-smart agriculture (CSA) (which includes the agriculture, forestry and fisheries sectors) at the local level contributes to meeting global objectives, primarily those of the United Nations Framework on Climate Change (UNFCC), the Convention on Biological Diversity (CBD) and the World Summit on Food Security (WSFS), leading to a sustainable development landscape.



CSA is built on three pillars (FAO, 2010), which focus on:

- **Sustainably increasing farm productivity and income**. Productivity must increase in order to secure enough food for our growing population.
- **Strengthening resilience to climate change and variability.** Climate change requires adaption of food production systems for resilience both at the livelihood level and at the ecosystem level.
- **Mitigating the contribution of agricultural practices to climate change through a reduction or removal of greenhouse gas emissions**. A reduction in greenhouse gas emissions and the agricultural carbon footprint is essential, which calls for changes of practices, including more resource efficiency, use of clean energy and carbon sequestration.

It therefore enhances the achievement of national food security and development goals, and reflects the realities of the local and field levels.

CSA differs from other concepts in that it addresses real-world situations, has multiple objectives and places the needs of the local stakeholders as the focal point, placing food security and climate change effects at the centre of these considerations. It is relevant to several international goals and process, for example, achieving food security, the Millennium Development Goals and those of the UNFCCC. It builds on and integrates existing knowledge and experiences, combined with the finance to achieve the objectives.

## RIO+20

Rio +20 constituted a global meeting of parties concerned with global environmental, social and economic challenges that are increasingly facing the world today. From the perspective of agriculture, fisheries and forestry, FAO and the Rome-based international agencies brought forward three main messages:

- Eradicating hunger and improving human nutrition are fundamental to achieving the Rio vision of sustainable development.
- For healthy people and healthy ecosystems, food consumption and production must be sustainable.
- More inclusive and effective governance of agricultural and food systems is essential to achieving the Rio vision.

This was therefore an occasion to address possible paradigm shifts, such as converging agendas on food and the environment, and diverging agendas on food security and agricultural production.

## FAO-ADAPT

FAO-Adapt is an organization-wide framework programme that gives general guidance and provides principles, priority themes, actions and implementation support to FAO's activities that are directly related to climate change adaptation. FAO-Adapt encourages activities in the sectors of agriculture, forestry and fisheries that increase sustainable production while strengthening the resilience of agricultural ecosystems in order to cope with the current and future climate change challenges. It is a part of a family of FAO climate-smart programmes designed to expand the capacity of Member Nations to implement climate change adaptation measures and assist them in making climate-smart decisions with regard to agricultural practices (FAO, 2011), including:

- Data and knowledge for impact and vulnerability assessment and adaptation.
- Institutions, policy and financing to strengthen capacities for adaptation.
- Sustainable and climate-smart management of land, water and biodiversity.
- Technologies, practices and processes for adaption.
- Disaster risk management.

## THE CASE FOR INVESTING IN RESILIENCE/CSA

There are a number of questions that need to be addressed when examining the case for investing in resilience and CSA:

- To what extent is capital for sustainable agriculture/land use a limiting factor?
- Risk management issues?
- Can sustainable agriculture be profitable?
- How can we engage private finance in an equitable and effective way?
- How do we measure success?
  - How many indicators do we need?
  - Is three enough?

## SOME WORDS ON UNFCCC PROCESS

The next COP (18) of the UNFCCC presents an opportunity to ensure that agriculture is included in the climate change negotiations. Although it is a long process, work must continue to establish a work programme on agriculture in Doha. In addition, the workshop on NAPs (National Action Plans) is also an opportunity to include agriculture and climate change considerations into national agendas.

## CONCLUSION

The quest for food security is the common thread that links the different challenges with a view to building a sustainable future. Eradicating hunger and improving human nutrition, creating sustainable food consumption and production systems, and building more inclusive and effective governance of agricultural and food systems are fundamental and at the heart of achieving the Rio+20 vision of a world with both healthier people and healthier ecosystems (FAO, 2012). CSA is a practice that can help us achieve this target. It embraces multiple objectives, it aims to increase agricultural productivity and farmers' income; strengthen the resilience of ecosystems and livelihoods to climate change; and reduce greenhouse gas emissions. It takes into consideration context-specific and locally-adapted actions and interventions, along the whole agricultural value chain. FAO promotes CSA through strengthening the knowledge base on sustainable practices, as well as on financial and policy options that would enable countries and communities to meet their food, water and nutritional security and development goals. CSA in FAO involves a people-centred approach, keeping farmers and those most vulnerable, including women, at the heart of dialogue, decision-making and action, and empowering them as critical agents of change. Finally, improving farmers' access to and awareness of available knowledge services, finance, agricultural inputs (e.g. seeds and fertilizers), and rights (e.g. land tenure rights) is key to the successful implementation of CSA strategies.

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# Risks, vulnerabilities and resilience in a context of climate change

*Vincent Gitz and Alexandre Meybeck*
*Agriculture and Consumer Protection Department, FAO, Rome*

Agricultural activities are by nature prone to risks and uncertainties of various nature, both biophysical, abiotic, climatic, environmental, biotic (pests, diseases) and economic. Many of these risks have a climatic component and most of them will be affected by climate change, either in intensity, scope or frequency.

The aim of this paper is not to review the increasing literature on risks, on vulnerability[1] and on resilience.[2] It is to articulate these broad notions in such a way that they can be of use to frame an approach applicable to concrete issues in the agricultural and food systems.

The impact of a risk depends on the shock itself and on the system to which it is applied. Depending on its vulnerability, the system will be more or less affected by the same shock. Depending on its resilience, it will recover more or less easily.

Climate change is expected to modify risks, vulnerabilities and the conditions that shape the resilience of agriculture systems. Climate change is also introducing new uncertainties.

Could building resilience to known risks be a way to build resilience to changing risks and to adapt to climate change? How to build strategies and policies for resilience of agriculture and related systems in the context of climate change?

To consider these questions, one has first to clarify how these notions of risk, vulnerability and resilience are connected, how they apply to systems, and to interlinked systems, and how environmental (biophysical), economic and social perspectives can interact.

Therefore, this paper aims towards a better understanding of "what adaptation means" and towards strategies to build resilience in making the following points:

1. Risks operate on **systems** and first one must have a good understanding of the systems to be considered.
2. Climatic risks and changes operate in the **middle of all other risks**, superpose with them and change them.
3. Before we come to "what we mean by resilience", we must explain the notion of **vulnerability.** To consider risks as they impact systems leads us to consider vulnerabilities. We will try to define what this notion covers and its dimensions.
4. **Building resilience** starts with reducing vulnerabilities: a system is more resilient if it is less vulnerable. But this is not enough. Resilience adds two dimensions: the

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[1] For a review on the notion of vulnerability, see Adger (2006) and Fellmann (2012).

[2] For a review on resilience from an operational point of view, see Martin-Breen. and Anderies (2011).

dimension of time and the need to deal with uncertainties. This is where **adaptive capacity** is key.

5. Finally we will draw some lessons for **strategies to build resilience** in the context of climate change.

## SOME DEFINITIONS AND PERSPECTIVES

### Definitions

"Risk" is used here to designate the potential of shocks and stresses to affect, in different ways, the state of systems, communities, households or individuals. Probability, uncertainty (when probabilities of occurrence or even nature of impacts are unknown), severity, economic scale, time scales and direct and indirect costs should be taken into account.

"Vulnerability" is the propensity or predisposition to be adversely affected (IPCC, 2012). It is a dynamic concept, varying across temporal and spatial scales and depends on economic, social, geographic, demographic, cultural, institutional, governance and environmental factors. Measuring vulnerability is complex as it needs to be considered across various dimensions.

"Resilience" is the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions (IPCC, 2012).

"Adaptive capacity", the capacity of a system to adapt in order to be less vulnerable, is a dynamic notion. It is shaped by the interaction of environmental, social, cultural, political and economic forces that determine vulnerability through exposures and sensitivities, and the way the system's components are internally reacting to shocks. In fact, it has two dimensions: adaptive capacity to shocks (coping ability) and adaptive capacity to change. The first dimension is related to the coping ability (absorption of the shock), the second dimension is related to time (adaptability, management capacity). Adaptations are manifestations of adaptive capacity (Smit and Wandel, 2006).

### Characterization of systems

Importantly, these notions of vulnerability and resilience are applied to systems[3], which means that first the system(s) to be considered (its components, their boundaries and delineation) has to be clarified in order to assess its vulnerability and/or resilience.

Systems can be embedded into one another, meaning that one system can be a component of a major system.

Systems can be delineated according to various perspectives (including expected functions), environmental, economic or social (including political and institutional), even though they are linked.

Food systems are by nature ecological, economic and social (Ericksen, 2008; Füssel and Klein, 2006). Each dimension has its own organization and interacts with the others. They

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[3] A system is a set of interacting and independent components that form an integrated whole, in interaction with the environment and other systems.

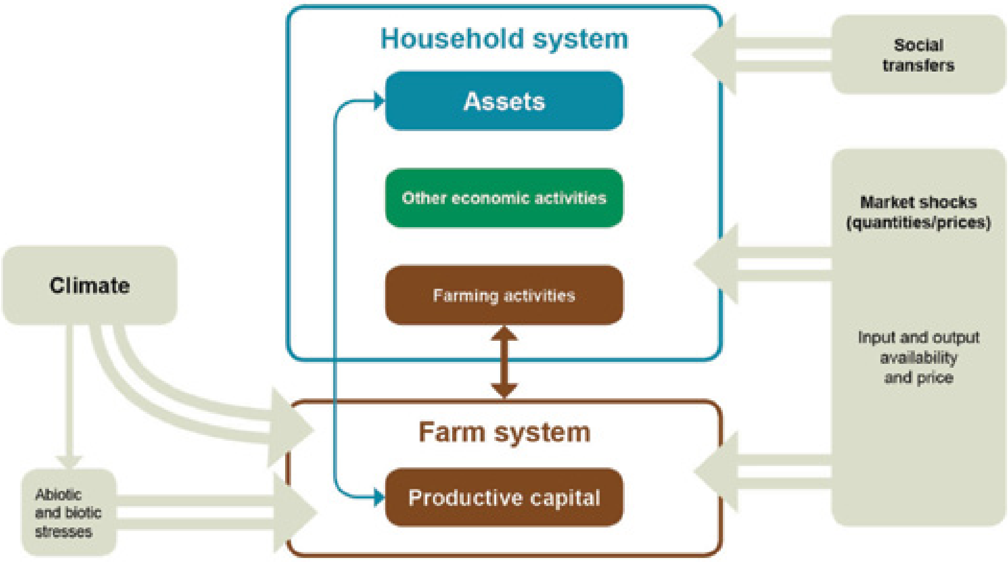

**Figure 1. Household and farm systems**

can be described and analysed in each of their dimensions. There are also theories attempting to understand and describe "complex systems" (Holling, 2001; Gunderson and Holling, 2001) particularly to better seize the concept of sustainability.

From a food production perspective, the smallest system would be the farm, integrated in a farming system and at the same time in a food chain, or food chains according to each production.

From a food security perspective, the smallest system would be the household (composed of individuals), which can be linked to a farm or farming activities (Figure 1), integrated in a social community and with other links, economic and social.

From a biophysical perspective, the farm has to be considered as part of a landscape, with different delineations according to various issues (water, biodiversity, etc.).

The food production systems and the food security systems, as well as the biophysical/environmental systems, are interlinked, and sometimes share some subcomponents.

For the three ranges of systems above, stemming from three different perspectives, we can define more local or elementary sets of systems (such as farms, households), and higher level systems that would be national, regional and global (Table 1 and Figure 2). In Table 1 and Figure 2, to simplify, we have considered a five-scale imbrication of systems.

**Table 1: Systems across dimensions and scales**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Food production | Farms | Farming systems and food chain(s) | National | Regional | Global |
| Food security | Households | Communities | National | Regional | Global |
| Biophysical | Farms | Landscapes | National | Regional | Global |

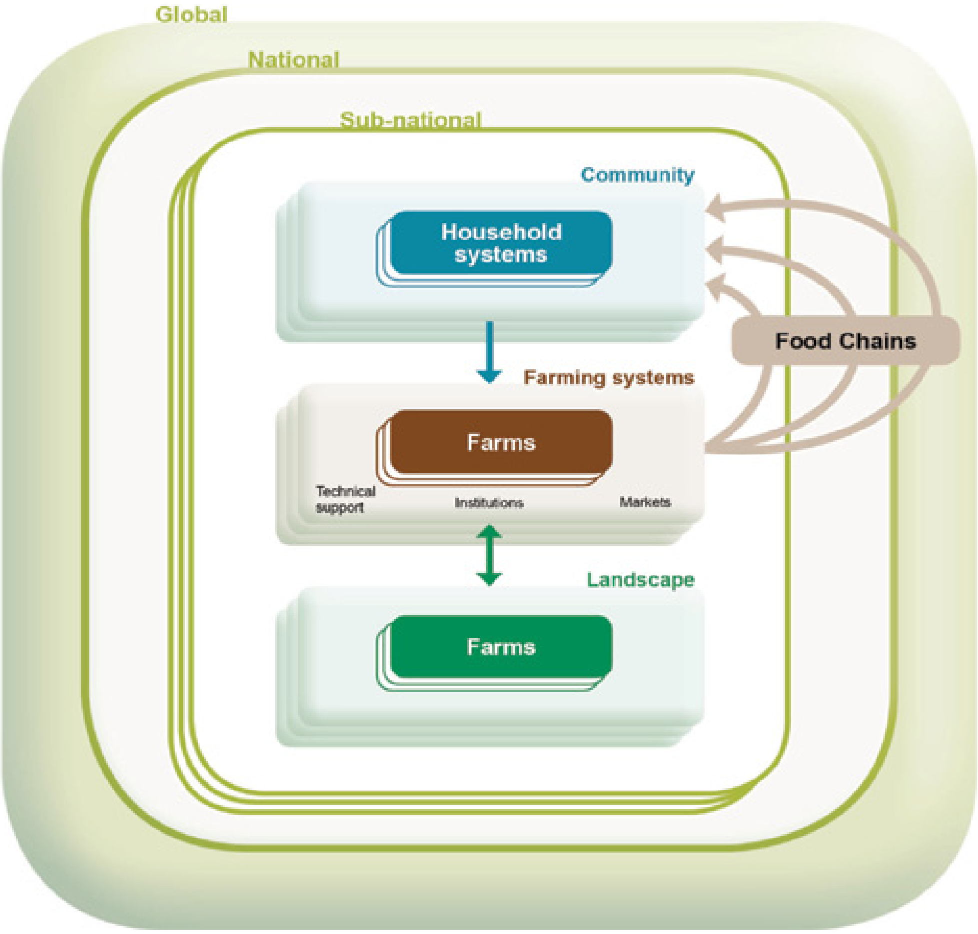

Figure 2. Imbrication of different systems across scales

## RISKS AFFECTING AGRICULTURE

### Various risks

Agricultural production is submitted to risks of various types: political instability, economic and price-related risks, climatic, environmental, pests and diseases, at different scales. Risks affecting yield in main staple crops are particularly important for smallholders, who tend to consume a large part of their own production. Farmers are also exposed to economic risks including land tenure insecurity, variations in access to inputs (fertilizers, seeds, pesticides, feed) in quantity and quality, and variations in access to markets.

Often risks of various types, when superposed, exacerbate their effects, as for example in the case where livestock that are already weakened by a lack of feed owing to a drought would be more prone to becoming infected by a disease. Also, after a poor harvest, seeds could be lacking for the next growing season.

Risks faced by producers not only compromise food security directly but also indirectly as they constraint agricultural development by preventing investment and access to credit.

**Table 2: Types of risks and potential impacts on farmers**

| Types of risk | Potentially influenced by climatic factors | Potential economic consequences on farmers | Potential long-term consequences |
|---|---|---|---|
| Input price increase | Yes (feed) | Yes, reduced income for farmers | When it affects investment (seeds, breeding stock) |
| Output price decrease | Yes | Yes, reduced income for farmers | Reduce incentive for investment |
| Weather shocks | Yes | Yes | Depending on type of shocks and productions |
| Plant pests | Yes | Yes, reduced yield | Yes. Pest could last. Loss of productive capital (trees). Potential trade barriers. |
| Animal diseases | Yes | Yes, reduced production. Loss of livestock. Potential trade barriers | Yes. Disease could last. Loss of productive capital. Potential trade barriers. |

Reducing the producers' vulnerability and strengthening their resilience to shocks is an essential part of any agricultural development policy.

Risks affecting agricultural activities are generally categorized according to the nature of the associated shocks: biophysical, economic, etc. (Eldin and Milleville, 1989; Holden, Hazell and Pritchard, 1991; Cordier, 2008; OECD, 2009). They are also often classified according to the intensity, frequency and predictability (degree of uncertainty) of the associated shocks. They can also be categorized according to their impacts: nature, but also importance, scope both in space and time (INEA, 2011).

All of these parameters not only characterize the risks and their potential impacts. Their apprehension is also necessary to shape the level and type of intervention needed to reduce them and/or to avoid that they have long-term consequences.

Based on a review of the literature, OECD identifies crop yield, output price and, to a lesser extent, input price as the major risks for crop producers (OECD, 2009). Livestock grazing systems are subject to much the same type of risks. Livestock systems that rely heavily on external feed are particularly subject to input price risk (OECD, 2009).

Weather is in itself a major cause of risk. It also has a major influence on most of the other production risks.

Climate changes will change the determinants of the risks that agricultural systems are facing. For example, it can manifest itself by changing the degree of uncertainty and predictability of previously existing risks.

The South Asian summer monsoon is critical to agriculture in Bangladesh, India, Nepal and Pakistan. Climate change could influence monsoon dynamics, a change of precipitation and delays in the start of monsoon season, with important impacts on agriculture, even for slight deviations from the normal monsoon pattern. Even if modelling studies are improving to assess how monsoon patterns might be affected by climate change, it remains that climate change adds here an important layer of uncertainty to previously existing risks (start of the monsoon, amount and pattern of precipitation).

Often, there can be very different perceptions of a risk depending on the angle of analysis, or depending on the point of view from which it is appraised or considered (risks bearer, impact bearer, vulnerability bearer, external actor, etc). One good example in that regard is

**Box 1: Drought terminology (from IPCC)**

In general terms, drought is a "prolonged absence or marked deficiency of precipitation", a "deficiency of precipitation that results in water shortage for some activity or for some group" or a "period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance" (Heim, 2002). Drought has been defined in a number of ways. "Agricultural drought" relates to moisture deficits in the topmost one metre or so of soil (the root zone) that impact crops, "meteorological drought" is mainly a prolonged deficit of precipitation, and "hydrologic drought" is related to below-normal streamflow, lake and groundwater levels. (IPCC, 2007a).

The socio-economic impacts of droughts may arise from the interaction between natural conditions and human factors, such as changes in land use and land cover, water demand and use. Excessive water withdrawals can exacerbate the impact of drought. (IPCC, 2007b).

the definition of "extreme events". A meteorological event can be described as "extreme" because of its intensity or because of its infrequency. Most often it is because of both. Moreover, intensity can be perceived and assessed as the intensity of the event/shock itself or by the importance of its effects, which depend on the vulnerability of the affected area and/or activity. In that respect agriculture is very specific because of its greater vulnerability to even slight changes in temperature or rain patterns, which can have devastating effects on crops, grasslands or forests. Changes in short-term temperature extremes can be critical, particularly at key stages of plant development (Gornall *et al.,* 2010). Therefore, describing the risk (intensity, frequency, probability, uncertainty) is not enough – one has to look at its transmission into the system considered, starting with impacts.

## Various impacts

A single stress/shock can have various impacts, of diverse nature and time scale, even considering a single simple farming system.

For instance, a drought in livestock grazing systems (see Figure 3) reduces the availability of water and grass – both directly and indirectly because, as the watering points are reduced, some pastures are no longer accessible – and so increases demand for feed at the very moment when there is less feed available. These drive a feed price increase, which forces livestock owners to sell their cattle. Massive sales while there is a reduced demand push cattle prices down, forcing to sell even more to buy feed. These effects on prices reduce farm and household income and assets. Moreover, they reduce the value of assets (livestock) and the productive capital for the future. Prolonged or repeated drought also has long lasting degrading effects on land: a combination of drought and overgrazing, particularly near watering points, destroys the vegetal cover, increasing soil erosion.

Assessing potential im-pacts of a stress on a system requires not only evaluating potential impact on each of the components of the system but also how it will change the relationships between the components of the system. It is particularly difficult for complex systems involving biophysical factors, as these cannot be totally reduced to a single dimension.

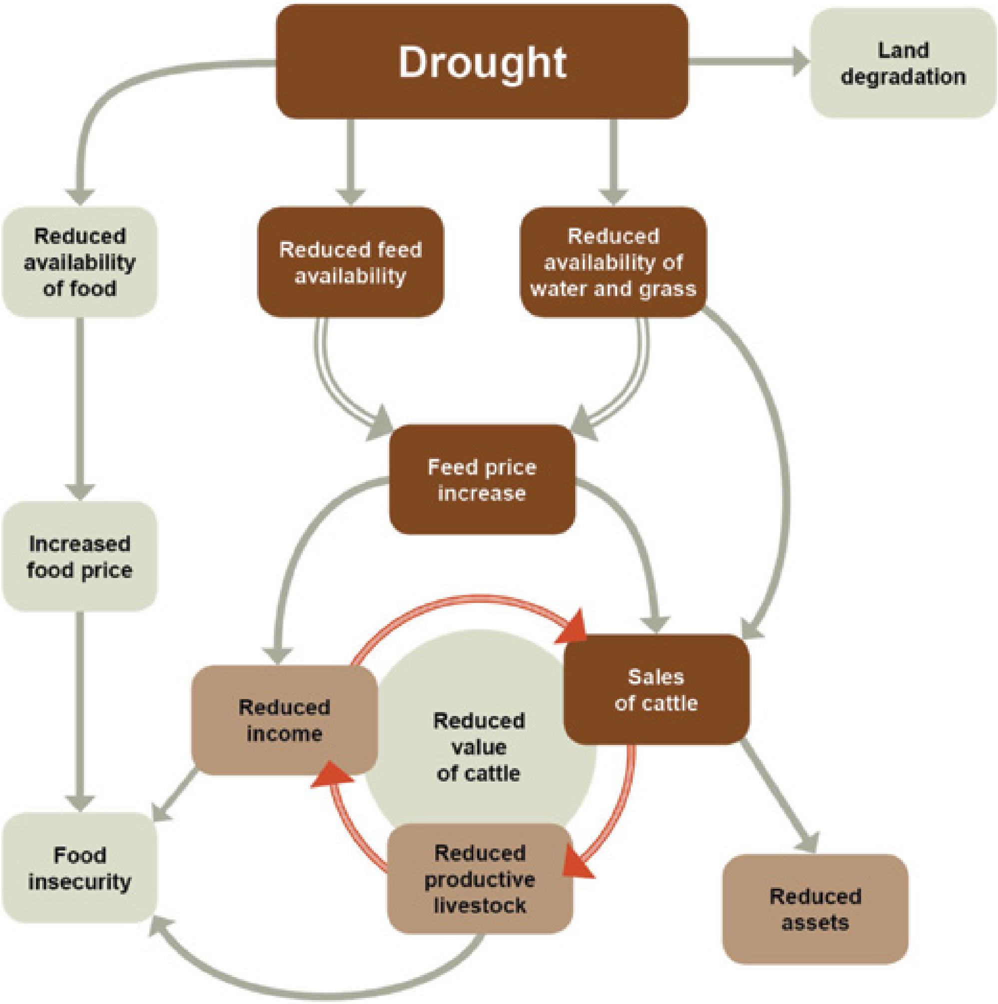

**Figure 3. Impacts of a drought on grazing systems**

Climate changes will have an effect on various components of each ecosystem, and on internal feedback loops (Figure 4). Some of these effects begin to be better understood and can be simulated, like effects on a single species, as the effect of higher average temperature on major crops, for instance. But effects on the whole system are much more difficult to predict. For instance, effects on pests and on their predators are much less known. And thus effects on their interrelationships, which drive the impact on crops, cannot be integrated in projections. Seemingly, climate change will affect both pollinators and the plants with which they interact (Kjøhl, Nielsen and Stenseth, 2011). Any disruption on their synchronicity could have a major effect on their relationships and thus on both of them. Therefore, the real effect of climate change on yields is not as known as the results from modelling crop reactions to climate change would make believe.

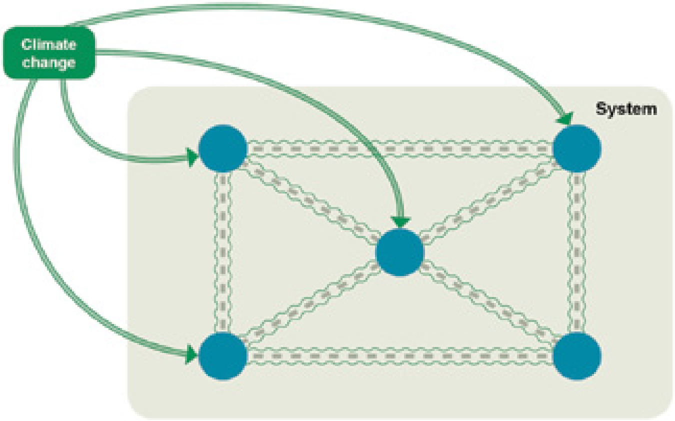

**Figure 4. Impacts of climate change on the components of a system and their interrelationships**

## Risk management

Risk management can involve various levels of systems and/or various dimensions. Solidarity at community level can help poorer households to support the effects and to recover (for instance, cattle lending practices in pastoral societies).

Some risks, such as plant pests and animal diseases, can spread from one farm or territory to another. Here risk management strategies, involving prevention, monitoring, early warning and early action can prevent the shock from spreading and having catastrophic effects. The **FAO Emergency Prevention System** (EMPRES) programme on locust in West Africa successfully avoids catastrophic crises such as the one of 2003–2005 for a cost of less than 0.6 percent of the value of the crops lost in 2003–2005 (Cossée, Lazar and Hassane, 2009).

Finally, in a given system, production shocks are transmitted in the economic and social dimensions. This transmission can be linear, amplified or reduced, depending on the policies and institutions that are in place.

# VULNERABILITIES

## Vulnerabilities and vulnerability

The net impact of a shock, ultimately depends not only on the intensity of the shock itself but also on the vulnerability of the system to this particular type of shock.

Vulnerability, as defined in the introduction of this paper, is a complex concept that needs to be considered across scales and across various dimensions. It can be defined as vulnerability of "what" to "what" (Carpenter *et al.*, 2001). But it is in fact more complex. The first "what" encompasses two dimensions: (i) the identification of the *system and components* that at the end "bear the vulnerability"; and (ii) the measure of the potential impact qualities/dimensions/units that characterize the entry, through a threshold, of the system/component into a degraded/impacted state: it can range from health to nutrition, injuries, revenue, assets, including social variables. This defines the "domains" of the vulnerability. The second "what" is either a single risk, or a set of risks, or a change in the context that shape existing risks.

Measuring and assessing vulnerability is a growing field of research, and goes outside the scope of this paper. The vulnerability of a system has to be contemplated given the whole set of risks (and related specific vulnerabilities) that affects it and that may have compensative, cumulative or amplifying effects. It also encompasses several dimensions: productive, economic, social. Therefore, there is potentially a wide range of metrics to assess vulnerability.

Means to be used to reduce the impact of a shock can either compensate for vulnerability (for instance, provide feed from another area in case of a localized drought) or reduce it in the long run, for instance by investing in more water points or in irrigation.

The degree of "specific" vulnerability of a system to a particular type of risk can be analysed as exposure and sensitivity to the potential shock that relates to this risk, and also depends on the "adaptive capacity" of the system to cope with the impact of the shock. The adaptive capacity itself can also be impacted by an external shock.

In a given system, shocks in one dimension can spread into another dimension: production shocks are transmitted in the economic and social domains. This transmission can be linear, amplified or reduced, depending on the policies and institutions that are in place.

For instance, a climatic shock, reducing yield in one area, can, at household level, be compensated for by trade, provided that trade is not impeded, and provided that households have the means to buy that food, using other sources of income, their own assets, or social transfers (safety nets).

In many cases, there can be amplifying or positive correlations between effects of shocks of diverse nature. In such cases, and conversely, reducing vulnerability to one kind of shock can also help to reduce (specific) vulnerability to another kind of shock. Vulnerability is also impacted by the various shocks; a drought increases vulnerability to the next drought. By decreasing the strength of the cattle, it also increases their vulnerability to diseases. By reducing assets of households, it also increases their vulnerability to any kind of shock.

Obviously, some characteristics of a system make it more or less vulnerable to a set of risks. A farm relying on a single crop is particularly vulnerable to a pest affecting this single crop or to a price drop of that crop. On the contrary, a much diversified system is less vulnerable to both pests and price fluctuations affecting specifically one type of production.

Finally, vulnerability can evolve in time as a system's adaptive capacity to a set of risks and shocks evolves in time, and also as its exposure and sensitivity to shocks can evolve with time. This is especially key in the context of climate change, which drives changes in the vulnerability of systems in two ways: (i) by introducing new risks; (ii) by changing the context and systems' responses to previously existing risks (including climate-related ones).

### Vulnerability at scales

Systems can be defined at various scales. As we have seen, an upper scale system is generally composed of different systems defined at lower scales (for instance, from a biophysical perspective, landscape systems are composed of farms).

The vulnerability of an upper scale system depends on the vulnerability of the subsystems that it includes. It also depends on how other systems, to which it is linked, including systems of a higher scale, will be vulnerable or insensitive to the shocks.

For example, the vulnerability of a farm to a certain risk is compounded of its own vulnerability and of the one of the landscape in which it is situated, and whose vulnerability is in turn compounded of its own, of the vulnerabilities of the various farms situated in it, and of the one of the system of higher level (e.g. the territory) in which it is situated.

A corn farm is more vulnerable to corn rootworm when corn is cultivated yearly on the same parcels; even more if it is close to other corn farms; even more if one of these farms is close to an airport; even more if this airport has flights arriving from a country where rootworm is common. In turn, a territory where a lot of farms, close to each other, cultivate corn, is more vulnerable to corn rootworm.

Seemingly, the adaptive capacity of a territory is compounded of the adaptive capacity of the farms that it encompasses, and of the systems that encompasses it (Figure 5).

A territory devoid of any system for monitoring animal diseases and for early action is more vulnerable to animal diseases. It makes all livestock producing farms of this territory more vulnerable to animal diseases.

From one level to another, vulnerabilities can either:

- add themselves;
- compensate each other;
- amplify each other.

A household relying on agricultural production is vulnerable to agricultural production shocks. A country relying on agricultural production is vulnerable to agricultural production shocks. Which makes households relying on agricultural production situated in countries relying on agricultural production even more vulnerable, because at the time of a major shock it is more difficult for the country to compensate.

Therefore, one way to reduce vulnerability can be to act on the transmission from one level to another. This is why, for instance, monitoring of diseases and plant pests, and early action to avoid their spread, is an essential way to reduce vulnerability at different levels.

Figure 5 is a schematic representation of the state of vulnerability of production systems: vulnerability of the farms, of the farming landscape (group of farms) and of the farming region/territory, for example the vulnerability at different scales to an animal

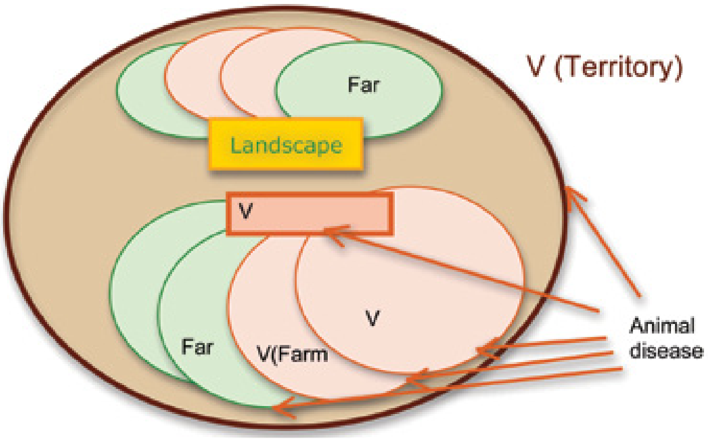

**Figure 5. Vulnerability and vulnerabilities at different scales**

disease. Towards the darker grey are more vulnerable units. Towards the light grey are less vulnerable units. The vulnerability of the landscape of farms depends of the vulnerability of each farm it contains and of the upper-scale vulnerability of the territory.

## RESILIENCE

Resilience can be described as the capacity of systems, communities, households or individuals to prevent, mitigate or cope with risk, and recover from shocks. At first approximation, resilience is the contrary of vulnerability, but importantly it adds a time dimension to the concept: a system is resilient when it is less vulnerable to shocks *across time*, and can recover from them.

We have seen that adaptive capacity encompasses two dimensions: recovery from shocks and response to changes. These two dimensions play an essential role towards resilience, both to recover from shocks and to adapt to change. Therefore, it ensures the "plasticity" of the system. For example, the organization of proper seed systems enables farmers having lost a crop to have seeds for the next season. It also enables them to have access to seeds adapted to new conditions.

We have seen that adaptive capacity can be impacted by shocks. Shocks hurting, directly or indirectly, an adaptive capacity have a long-term effect and are therefore one of the first concerns to ensure resilience.

For instance, after a severe drought, pastoralists are more vulnerable to a new drought, because they have less productive cattle. They have also less adaptive capacity, less capacity to recover to shocks and eventually to change because they have lost assets (Figure 4). They are less resilient.

As for vulnerability, resilience can be specified as "resilience of what to what" (Carpenter *et al.*, 2001). However, focusing on specified resilience may cause the system to

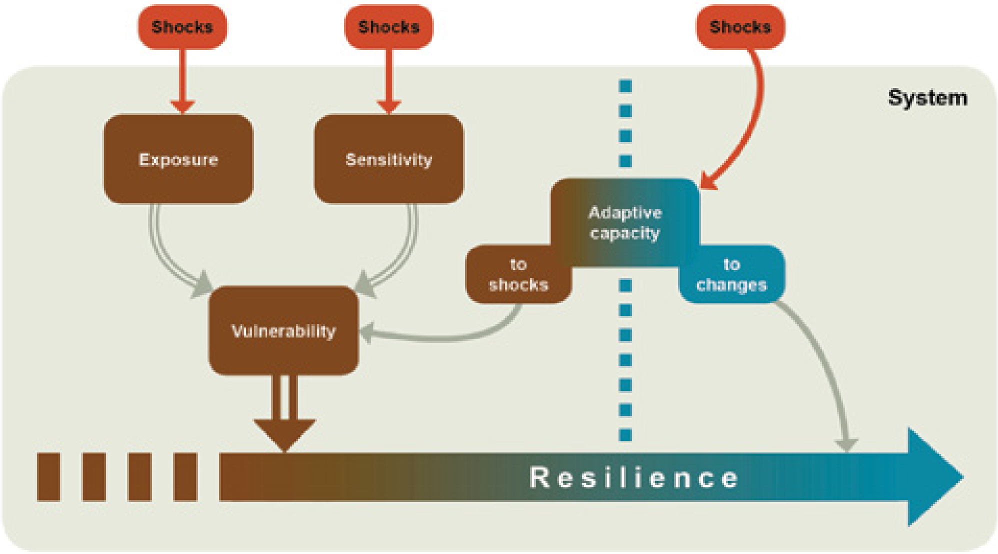

**Figure 6. Vulnerability and resilience**

lose resilience in other ways (Cifdaloz *et al.*, 2010). This is why general resilience can be described as being "about coping with uncertainty in all ways" (Folke *et al.*, 2010).

As for vulnerability, resilience can be considered in various dimensions – biophysical, economic and social and at various scales. And as for vulnerability, the way the various dimensions and scales interact is crucial, precisely because of the importance of general resilience to cope with uncertainty. For instance, Karfakis *et al.* (2011) shows that increasing the level of education of farmers can be an efficient mean for reducing farmers' households vulnerability to climate change.

Resilience puts a greater emphasis on the capacity of a system to recover and transform itself in the long term, to adapt to its changing environment, in a dynamic perspective. It therefore implies that it is not only shocks that have to be considered, as a change relative to an average, but also the change of the average itself, ultimately the question being until what point a system can adapt before changing to another type of system.

## BUILDING RESILIENCE

To a great extent, increasing resilience can be achieved by reducing vulnerabilities and increasing adaptive capacity. This can be achieved by reducing exposure, reducing sensitivity and increasing adaptive capacity, for every type of risk. It can act in each domain, either biophysical, economic and social. One way to achieve better resilience is to reduce transmission of shocks between types of risks, between scales and between domains and to organize compensation between scales (for instance transport of feed) or between domains (for instance safety nets) to avoid cumulative and long-term effects.

In this section we make an attempt to describe the bricks that can be used to build strategies for resilience.

### Three ways to build resilience

In a first approximation we can identify the following three ways to build resilience:

1. Reduce exposure. There is a fundamental difference between climatic and non-climatic shocks in this regard because most of the shocks on-farm can be reduced at the source, or limited in their extension, contrary to climatic shocks. Here the best example is probably the eradication of rinderpest, which has totally suppressed a major risk for livestock and those depending on it.
2. Reduce the sensitivity of systems to shocks. Sensitivity to drought can, for instance, be reduced by using drought-resistant varieties or keeping stocks of hay.
3. Increase adaptive capacity. This includes considering the modifications of a system taking into account all the potential shocks and changes altogether (to take into account compensating, cumulative or exacerbating effects).

But all of this is not enough. To ensure resilience, the three ways of actions above have to be considered *through time*, and given *uncertainties*.

### Building resilience through time.

First, there is the need to build adaptive capacity not only to existing risks and shocks (coping capacity), but also *to changes, in an evolving context* (Figure 5).

Second, there is the need to consider that strengthening resilience, in real life, has to be done *at the same time as the shock occurs, since they occur all the time*. This is where we can separate between *ex-ante* (A), during shock (B), and *ex-post* (C) actions to build resilience:

1. *Before the shock*, by increasing, *ex ante*, the resilience of productive or livelihood systems to existing or emerging risks: for example, through putting in place systems for the early detection of emerging risks, or through the reduction or elimination of a specific risk.
2. *During the shock*, ensuring that affected agents (farmers, communities, small-scale food processors, poor consumers) can benefit from continuing access to food and adequate diets, and keep their asset levels and means of livelihood, including by safety nets.
3. *After the shock*, helping systems to recover and build adaptive capacity. Actions can be pursued that progressively reduce the effect of the previous shock, reduce the exposure and sensitivity to future ones, and/or that increase the adaptive capacity of a system to future shocks in a changing context (*adaptive capacity to changes*). Restoration measures such as grassland restoration measures are a good example of this.

## Addressing uncertainties: a condition to build resilience

Finally, we have to take into account that occurrence of shocks is not certain: either their own nature, or the nature or size of the impacts, can be uncertain, or their occurrence in time is generally not known. Therefore building resilience goes with the need to *anticipate* within uncertainty, within the system, or across scales.

In that sense, specific risk monitoring not only reduces vulnerability but also increases resilience as it allows anticipating risks and their change.

A good example of actions to build resilience in the face of uncertainties owing to climate change is in the domain of genetic resources. If climate changes, farmers might need to rely on different genetic resources, some that are already used elsewhere, or some other species or varieties that were considered minor but that could appear to be more adapted. To do so, there is the need to be able to rely on the largest pool of genetic resources. Genetic resources, which are also threatened by climate change, are indispensable for adaptation. We need to keep very diverse genetic material, including traditional and improved crop varieties and their wild relatives. They are adapted to specific conditions, have been selected for different uses, and constitute the reservoir from which varieties can be developed to cope with the effects of climate change such as drought, shortening of the growing season and increased incidence of pests and diseases. Preserving genetic resources increases the resilience potential of the whole system. To make this potential effective, genetic resources have to be accessible to farmers where they are needed: it is not enough to have the appropriate genetic resources in a gene bank or a research centre. They have to be multiplied and distributed, which require plant breeders, seed enterprises and the proper legal system to certify their quality and the accuracy of the genetic information. All these actors and elements constitute “seed systems” that enable farmers to have the seeds they need. Regional harmonization of seed rules and regulations is also essential, particularly as crops will move, to adapt to climate change.

**Box 2. Risks and adaptation measures: the role of amplifying effects**

Let us call R the risk, S the shocks (materialization of the risk), V the Vulnerability, I the net total impact on the system of the sum of shocks (materialization of the vulnerability).

Let us assume for the sake of simplification that there are climatic risks and shocks (Rc and Sc) and non-climatic risks and shocks (Rn and Sn)

We can write $I = f(Sc, Sn)$

and $V = g(Rc, Rn)$

where f and g are functions characteristic of the system that take into account its exposure, sensitivity and degree of adaptive capacity to risks and shocks.

An adaptation measure is a transformation of the system towards functions fa and ga whereby in principle impacts of climatic shocks are lower, and vulnerability is reduced, *everything else being equal.*

$Ia = fa(Sc, Sn)$

$Va = ga(Rc, Rn)$

where $Ia(Sc, Sn) < I(Sc, Sn)$ and $Va(Rc, Rn) < V(Rc, Rn)$ for all Sn and Rn

Now let us suppose that in first approximation we can write:

$F(Sc, Sn) = \text{alphac}\ Sc + \text{alphan}\ Sn + \text{beta}\ Sc\ Sn$

Then a climate change adaptation measure could be a measure that either acts to reduce alphac, or to reduce beta.

## Comprehensive strategies to build resilience through scales and dimensions

### a) Reduce, or take account of, amplification effects

When there are amplifications effects across risks and different kinds of shocks (economic, climatic, etc.), a reduction of non-climatic risks that act as a multiplier of climatic shocks can be a way to reduce the impact of climate change and therefore is an adaptation measure (Box 2).

### b) Organize compensation

The exposure, sensitivity and adaptive capacity of a system are often the (complex) result of the way internal components of a system interact. Internal components of the system can be organized, or interventions can be applied to key components of the systems or to their interplay, to put in place compensation mechanisms that make the overall system less exposed, less sensitive and/or with more capacity to adapt.

To take an easy example, a household whose main activity is farming is less vulnerable to drought if it has non-farming income or assets that are outside farming activities.

As we have seen, the vulnerability of a system is also dependent of its relationships with subsystems, to other similar systems at the same level, or to systems at a higher level. Therefore, resilience can also be increased by organizing compensation across scales and with other systems.

Trade could compensate for a shock on production in a given area, provided that there are no barriers to it and that poor consumers can afford to buy traded products at the time when their income is lower and prices higher.

**Box 3. Enhancing resilience in pastoral systems**

Improved grazing management could lead to greater forage production, more efficient use of land resources, and enhanced profitability and rehabilitation of degraded lands and restoration of ecosystem services. Grazing practices can be used to: stimulate diverse grasses, improve nutrient cycling and plant productivity and the development of healthy root systems; feed both livestock and soil biota; maintain plant cover at all times; and promote natural soil-forming processes.

Hardiness of local cattle is essential for their very survival, especially considering potential degradation of climate conditions (increased risk of drought). In particular, capacity to walk long distances in order to find grass far from water points is essential. Improving the efficiency of local cattle by selection on productivity in the breed and better health and feeding conditions rather than by cross-breeding could preserve the genetic specificities that are essential to the resilience of grazing systems in arid conditions.

This is where safety nets can play an essential role.

Finally, sustainable management of forests (Braatz, 2012) and sustainable management of fisheries (De Young, 2012) are also good examples where the actions towards resilience in one domain of vulnerability, starting by the biophysical domain, have also positive effects on the resilience and vulnerability in other domains (social/economic).

### c) From risks and vulnerabilities to policies and tools

While the reverse approach (from tools and policies to their impact on vulnerabilities) is often the major one followed, it results from the above that, in the climate change context, the identification and proper understanding of all the risks, impacts, vulnerabilities, over systems, in various dimensions, and how climate change might act on them, is rather a necessary precursor to consideration of tools and instruments, policies and their targets, and integration in a comprehensive approach towards resilience

Strategies for resilience should combine a set of specific policies targeted to address specific agents or components of systems, categories of risks, domains of vulnerability, and ways of action of the tools.

To ensure their proper use within a comprehensive strategy, there is an immense value added in clarifying, for each policy/tool, the ways of action of the tools and policies, and primarily the agents affected.

Policies targeted at farmers can include measures aiming at building economic resilience at farm level either by increasing income, by promoting diversification (especially if the risks affecting each activity are not correlated) or by insurance (in certain cases). They also include measures to reduce or eliminate specific risks, such as plant pests and animal diseases, including advanced observation networks for quick response. Other measures either prevent the loss of productive assets, such as feed banks for livestock during droughts, or enable quick recovery, such as availability of seeds.

Policies should also address risks along the food chain (including for small-scale food producers), including storage, post-harvest losses and food safety risks. Prevention of food

**Box 4. Change of system: from slash and burn to agroforestry in Central America**

Since 2000, FAO has initiated special programmes for food security with the Governments of Guatemala, Honduras, Nicaragua and El Salvador. These programmes worked together, sharing practices, experiences and results, to improve and develop agroforestry systems in the subregion.

Agroforestry systems are promoted to substitute traditional slash and burn systems, particularly on slopes. They are at the same time more efficient and resilient.

In traditional slash and burn systems, a family needs close to 6 hectares to maintain itself on a diet of maize and beans: it exploits the parcel for two years, and then sets it aside for 14 years.

In agroforestry systems, a parcel is exploited for ten years, producing, along with maize and beans, a variety of other products, often including also livestock, then is set aside for only five years. A family thus needs 1.4 hectares to sustain itself, and with a much more varied and balanced diet. Land is therefore almost four times more efficient.

This is also because, in agroforestry systems, yields (which are comparable the first year) do not decline over time as they do very rapidly in slash and burn systems. In fact, they can even slightly increase over time in agroforestry systems. Productivity of labour and of capital are also higher in agroforestry systems.

Costs are reduced, especially in fertilizers, thanks to more organic matter in the soil and better use of nutrients by the plants.

At community level, diversification of production triggers the development of local markets.

So agroforestry systems are very efficient: for food security, for the environment, in terms of resource use.

Agroforestry systems are also much more resilient:

- Yields are less variable, (also thanks to better humidity retention).
- They provide for more diverse productions: a buffer against both individual crop's yield variability and price volatility.
- They offer diversified sources of income, including through selling wood for various uses (and at various time scales), which can also buffer some economic shocks.
- They protect the soil from erosion, which is a major concern in these areas. Studies have shown that erosion is reduced in agroforestry systems by a factor of more than ten..

safety risks or effectiveness to handle large-scale food safety emergencies will depend on the services available (inspection and analytical capacities, information sharing, health services).

Policies targeted at consumers would use measures specifically designed to address access to food that is nutritionally adequate, safe and culturally appropriate.

The efficiency of any specific risk management policy is largely dependent on the existence of enabling policies, institutions, coordination mechanisms and basic infrastructure. For example, markets and transport have an important role in diluting the impact of a shock over greater areas.

## CONCLUSION

Climate change is expected to introduce new risks for agricultural production and to modify existing ones. Climatic models cannot predict future risks with a sufficient precision to enable decision-makers at local level to exactly address them.

The impact of a risk on a system depends on the shock itself and on the vulnerability and resilience of the system. An analysis of the notions of vulnerability and resilience, as applied to agricultural and food systems, in their various dimensions (biophysical, economic and social), taking into consideration the imbrications of systems of various scales (for instance from farm to landscape), shows that the interactions between dimensions and between scales can play a crucial role to reduce vulnerability and increase resilience.

The notion of resilience itself is particularly powerful to bring together measures intervening into very different dimensions, biophysical, economic and social. It also enables clarification of the relationships between "specific" vulnerabilities and resilience and how addressing known risks can enable strategies to be devised to build general resilience in order to cope with uncertainty.

As such, it provides an efficient way for "no regret" adaptation. A crucial element of it could be to better manage known risks, whether climatic or not, to get prepared for future, uncertain risks and changes.

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# The assessment of climate change-related vulnerability in the agricultural sector: reviewing conceptual frameworks

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## 1. CONTEXT AND OBJECTIVES OF THE PAPER

Climate change is expected to impact on the agricultural sector in multiple ways, among others through increased variability with regard to temperature, rain, frequency and intensity of extreme weather events, changes in rain patterns and in water availability and through perturbations in ecosystems. The main effects on agricultural production are expected to be an increased variability of production, decrease of production in certain areas and changes in the geography of production. One way to cope with the challenges comprised by climate change is to build resilience for adaptation in the agriculture sector.

The OECD and the FAO are working together on an analytical report that focuses on building resilience in agricultural production systems in the context of climate change. The report intents to respond to key policy concerns regarding climate change, its impact on agriculture and the implications for food security. For the analytical report, a general overview on climate change change-related risks and vulnerabilities will be provided by other contributors to the report. Furthermore, in order to illustrate specificities relative to addressing risks and vulnerability in agriculture, four thematic case studies will be carried out, capturing agricultural production systems in both developed and developing countries.

In the context of the analytical report the objective of this paper is to provide a review of conceptual frameworks for the assessment of climate change-related vulnerability and give some examples of their application to the agricultural sector. Therefore the paper reviews existing interpretations, concepts and frameworks of vulnerability approaches in the climate change context. However, it has to be highlighted that the paper does not attempt to give a complete literature review on the vast interpretations and alternative concepts of vulnerability approaches. Instead, the paper rather aims to give a brief overview on main characteristics in vulnerability approaches, highlight major differences in alternative vulnerability interpretations, and give some reference examples for the agricultural sector. In doing so, the paper aims to: (i) help reduce complexity by easing understanding and communication; (ii) assist the comparison of different vulnerability approaches to identify differences and detect gaps; and (iii) serve as a guiding principle and useful reference for vulnerability assessment in the agricultural sector.

The paper is structured as follows. The basic meaning of vulnerability and its three components in the climate change context (exposure, sensitivity and adaptive capacity) are described and the difference between adaptive capacity and coping range is depicted in section 2. In section 3 alternative interpretations and concepts of vulnerability are presented, highlighting the relative roles of natural and social science within the different concepts. Section 4 gives a further characterization of current and future vulnerability in order to underline the differences with regard to the temporal reference in vulnerability concepts and interpretations. Some methods for assessing vulnerability to climate change are noted in section 5, focusing briefly on the use of indicators, model based assessments and stakeholder involvement in vulnerability assessments. Section 6 briefly refers to the importance of documenting data constraints and uncertainties related to an assessment of vulnerability. Section 7 presents concluding remarks and a framework table with the elements that have to be considered and addressed in assessments of climate change-related vulnerability in the agricultural sector.

## 2. WHAT IS VULNERABILITY TO CLIMATE CHANGE?

The literature provides a vast variety of definitions for vulnerability, mostly depending on the disciplines of their origin (Adger, 2006). Nelson *et al.* (2010) pointed out that definitions of vulnerability should not be confused with conceptual frameworks. While definitions describe the components of vulnerability, conceptual frameworks give meaning to the definitions so that they can be analysed according to the analytical context in a transparent and repeatable way (Nelson *et al.*, 2010). However, it is essential first to clarify and understand what is meant when vulnerability is spoken and written about in the climate change context (Eakin and Luers, 2006; Janssen and Ostrom, 2006). A consistent and transparent terminology helps to facilitate the collaboration between different researchers and stakeholders, even if there are differences in the conceptual models applied (Downing and Patwardhan, 2005; Füssel, 2007; cf. Laroui and van der Zwaan, 2001; Newell *et al.*, 2005).

The Intergovernmental Panel on Climate Change (IPCC) is considered to be the leading scientific international body for the assessment of climate change, and consequently the starting point for this paper is vulnerability as defined by the IPCC. According to the IPCC (2007) definition, vulnerability in the context of climate change 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". Thus, agricultural vulnerability to climate change can, for example, be described in terms of exposure to elevated temperatures, the sensitivity of crop yields to the elevated temperature and the ability of the farmers to adapt to the effects of this exposure and sensitivity by, for example, planting crop varieties that are more heat-resistant or switching to another type of crop.

The definition of the IPCC (2007) specifically highlights three components of vulnerability in the climate change context: exposure, sensitivity and adaptive capacity

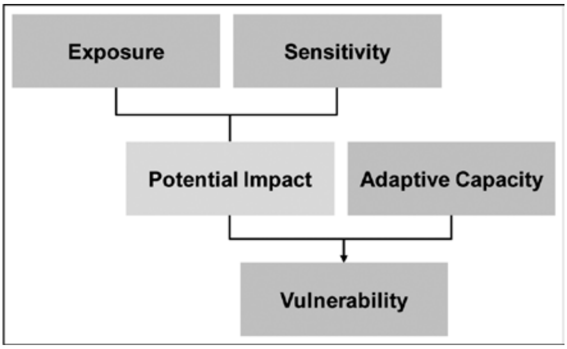

**Figure 1. Vulnerability and its components**
*Source*: Modified from Allen Consulting (2005).

(graphically depicted in Figure 1). It implies that a system is vulnerable if it is exposed and sensitive to the effects of climate change and at the same time has only limited capacity to adapt. On the contrary, a system is less vulnerable if it is less exposed, less sensitive or has a strong adaptive capacity (Smit *et al.*, 1999; Smit and Wandel, 2006).

In the climate change context, *exposure* relates to "the nature and degree to which a system is exposed to significant climatic variations" (IPCC, 2001). Exposure represents the background climate conditions and stimuli[1] against which a system operates, and any changes in those conditions. Thus, exposure as a component of vulnerability is not only the extent to which a system is subjected to significant climatic variations, but also the degree and duration of these variations (Adger, 2006). For vulnerability assessments the climatic variations can be aggregated as climate variability or specific changes in the climate system (e.g. temperature increases, variability and change in rainfall, etc.). It has to be noted that systems are often exposed to natural climate variability, independent of future climate changes; however, climate change can alter and increase the future exposure (Lavell *et al.*, 2012). With regard to exposure it is also important to define the exposure unit, i.e. the activity, group, region or resource that is subjected to climate change (IPCC, 2001).

The *sensitivity* of a system to climate change reflects the "degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)" (IPCC, 2007). Sensitivity reflects the responsiveness of a system to climatic influences, and the degree to which changes in climate might affect it in its current form. Thus, a sensitive system is highly responsive to climate and can be significantly affected by small climate changes.

Exposure and sensitivity together describe the potential impact that climate change can have on a system. However, it has to be noted that even though a system may be considered as being highly exposed and/or sensitive to climate change, it does not necessarily mean that it is vulnerable. This is because neither exposure nor sensitivity account for the capacity of a system to adapt to climate change (i.e. its adaptive capacity), whereas vulnerability is the net impact that remains after adaptation is taken into account (Figure 1). Thus, the adaptive capacity of a system affects its vulnerability to climate change by modulating exposure and sensitivity (Yohe and Tol, 2002; Gallopin, 2006; Adger *et al.*, 2007).

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[1] Climate-related stimuli are "all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes" (IPCC, 2001).

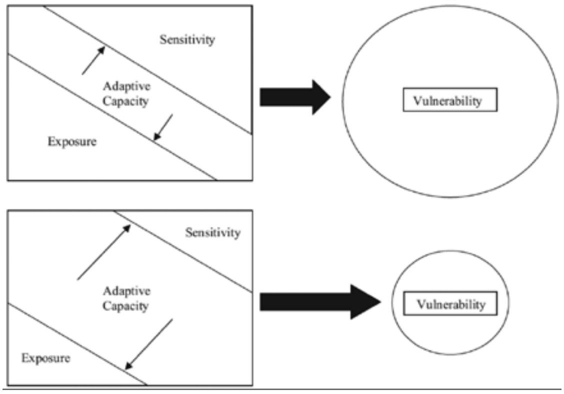

**Figure 2. The basic role of adaptive capacity in influencing vulnerability**
*Source*: Engle (2011).

The IPCC (2007) defines *adaptive capacity* as the ability (or potential) of a system to adjust successfully to climate change (including climate variability and extremes) to: (i) moderate potential damages; (ii) to take advantage of opportunities; and/or (iii) to cope with the consequences (IPCC, 2007). Adaptive capacity comprises adjustments in both behaviour and in resources and technologies (Adger *et al*., 2007). Recent literature emphasizes the importance of socio-economic factors for the adaptive capacity of a system, especially highlighting the integral role of institutions, governance and management in determining the ability to adapt to climate change (Smith and Pilifosova, 2001; Brooks and Adger, 2005; Adger *et al*., 2007; Engle, 2011; Williamson, Hesseln and Johnston, 2012). Accordingly, the adaptive capacity of a system can be fundamentally shaped by human actions and it influences both the biophysical and social elements of a system (IPCC, 2012). Research points out that some socio-economic determinants of adaptive capacity are generic (like, for example, education, income and health), whereas other determinants are specific to particular climate-change impacts such as floods or droughts (e.g. institutions, knowledge and technology) (Adger *et al*., 2007). In general, the determinants are not independent of each other nor are they mutually exclusive as, for example, economic resources facilitate the implementation of new technologies and may ensure access to training opportunities. Lower levels of adaptive capacity in developing countries are very often associated with poverty (Handmer, Dovers and Downing, 1999; IPCC, 2012).

Adaptive capacity is generally accepted as a desirable property or positive attribute of a system for reducing vulnerability (Engle, 2011). The more adaptive capacity a system has, the greater is the likelihood that the system is able to adjust and thus is less vulnerable to climate change and variability. The basic role of adaptive capacity in influencing vulnerability is depicted in Figure 2.

Vulnerability, its three components (exposure, sensitivity, adaptive capacity) as well as their determinants are specific to place and system and they can vary over time (i.e. they are dynamic), by type and by climatic stimuli (e.g. increasing temperature, droughts, etc.) (Smit and Wandel, 2006; Adger *et al*., 2007). Thus, vulnerability is context-specific, and the factors that make a system vulnerable to the effects of climate change depend on the nature of the system and the type of effect in question (Brooks, Adger and Kelly, 2005), i.e. the factors that make farmers in semi-arid Africa vulnerable to drought will usually not be identical to those that make farmers in Northern Europe vulnerable to extreme weather events (cf. Schröter *et al*., 2005a; Challinor *et al.,* 2007).

### *Adaptive capacity versus coping range*

It is important to distinguish between adaptive capacity and coping range because both concepts are associated with different time-scales and represent different processes (Smithers and Smit, 1997; Folke *et al.*, 2002; Eriksen and Kelly, 2007). A certain extent of variability is an inherent characteristic of climate, and most social and economic systems (including agriculture) are able to cope with some variations in climatic conditions – however mostly not with extremes of climate variability. The capacity of a system to accommodate deviations from "normal" climatic conditions describes the "coping range", which can vary among systems and regions. Towards the edges of the coping range outcomes might become negative but are still tolerable, whereas beyond the coping range (i.e. beyond the vulnerability or critical threshold) the tolerance of the system is exceeded and it runs into a vulnerable state (Smit and Pilifosova, 2001; Yohe and Tol, 2002; Jones and Mearns, 2005; Carter *et al.*, 2007; see Figure 3). For example, agricultural activities depend on local weather and climate conditions and can cope with some variability in these conditions, e.g. if it rains more or if it is drier over a given period of time (such as a specific month, season or year). However, if the conditions become too extreme (e.g. heavy rainfall, floods or extended droughts) and exceed the coping range, then this may result in severe effects for productivity levels and diminish livelihoods.

Understanding the coping range and vulnerability thresholds of a system is a prerequisite for the assessment of likely climate change impacts and the potential role of adaptation. Coping range and adaptive capacity of a system are certainly related, but it is important to distinguish between the two concepts when attempting to measure the ability of a system to respond to adverse consequences of climate change (Eriksen and Kelly, 2007). The concept of the coping range is a practical conceptual model because: (i) it fits the mental models that most people have with regard to risk; and (ii) it helps to link the understanding of current adaptation to the climate and adaptation needs under climate change (Jones and Boer, 2005; Jones and Mearns, 2005; Carter *et al.*, 2007). In contrast, adaptive capacity defines: (i) the preconditions (including social and physical elements) that are necessary to enable adaptation; and (ii) the ability to mobilize these elements (Nelson, Adger and Brown, 2007).

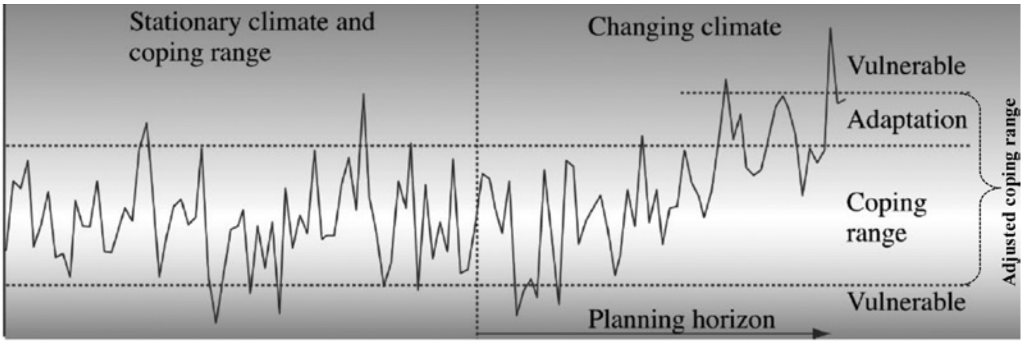

**Figure 3. Relationships between climate change, coping range, vulnerability thresholds and adaptation**

*Source*: Slightly modified from Jones and Mearns (2005) by adding the adjusted coping range.

Adaptive capacity represents the potential of a system to adapt rather than the actual adaptation (Brooks, 2003). In turn, adaptation represents the adaptation actually realized or aimed at to be realized in the future. This implies that through adaptation the coping range of a system can be expanded (or adjusted). Thus, the coping range as presented in the left part of Figure 3 represents the capability of a system to deal with current variations in climatic conditions. This coping range can be adjusted through adaptation, which in turn reduces the vulnerability of a system in the future (right part of Figure 3).[2] Hence, the coping range represents one component of adaptive capacity (with the adaptive capacity going beyond the actual coping range) and any adaptation can only take place within the adaptive capacity of a system.

## 3. ALTERNATIVE INTERPRETATIONS AND CONCEPTS OF VULNERABILITY: THE RELATIVE ROLE OF NATURAL AND SOCIAL SCIENCE

Similar to the variety of vulnerability definitions, the literature provides a vast variety of interpretations and alternative concepts of vulnerability. The concepts often originate from different academic disciplines and professional fields of practice and they often differ with regard to their unit of analysis (e.g. individual, household or region) and methods (Adger, 2006; Füssel and Klein, 2006; O'Brien *et al.*, 2007; Pearson and Langridge, 2008). The concept of climate change-related vulnerability has been comprehensively reviewed by many authors (see, for example, Kelly and Adger, 2000; Alwang, Siegel and Jørgensen, 2001; Brooks, 2003, Adger, 2006; Füssel and Klein, 2006; Eakin and Luers, 2006; Eriksen and Kelly, 2007; O'Brien *et al.*, 2007). Different concepts and interpretations of the character and cause of vulnerability produce different types of knowledge and therefore also result in different accentuations of strategies for reducing vulnerability (Kelly and Adger, 2000; Füssel, 2007; O'Brien *et al.*, 2007; Maru, Langridge and Lin, 2011). Moreover, the broad characteristics of alternative vulnerability interpretations can be quite confusing, and even more so in the climate change area, where researchers and stakeholders with different background knowledge collaborate. Therefore, it is not only beneficial but important to identify the thinking behind specific vulnerability analyses and to highlight the major differences in alternative vulnerability interpretations (Eakin and Luers, 2006; Janssen and Ostrom, 2006). Two of the most prominent vulnerability concepts in the context of climate change are outcome and contextual vulnerability, which differ mainly owing to their interpretation of vulnerability as being the end-point or the starting point of the analysis. Both concepts are graphically represented in Figure 4.

*Outcome vulnerability* (also known as the *"end-point" interpretation*) is a concept that considers vulnerability as the (potential) net impacts of climate change on a specific exposure unit (which can be biophysical or social) after feasible adaptations are taken into account. Thus, the outcome approach combines information on potential biophysical

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[2] It has to be noted that while the critical threshold in Figure 3 is held constant, in the real world coping ranges are not necessarily fixed over time and can dynamically respond to internal processes in addition to external climatic and non-climatic drivers (Yohe and Tol, 2002; Jones and Boer, 2005; Smit and Wandel, 2006; Carter *et al.*, 2007).

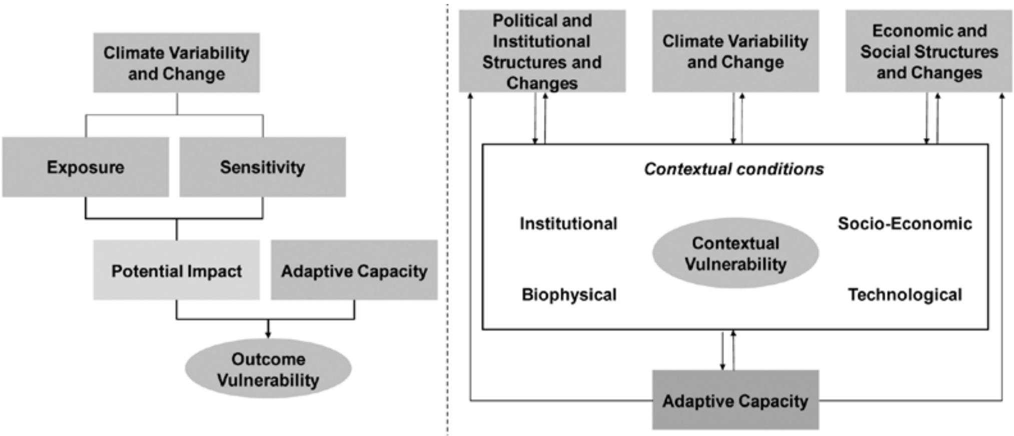

**Figure 4. Outcome and contextual vulnerability**
Note: The IPCC definition of vulnerability to climate change as presented in Figure 2 corresponds to outcome vulnerability (left part of Figure 5)
*Source*: Adjusted from Allen Consulting (2005) and O'Brian *et al.* (2007).

climate impacts with information on the socio-economic capacity to cope and adapt (Kelly and Adger, 2000; Füssel, 2007; O'Brien *et al.*, 2007).

Based on natural science and *future* climate change model scenarios, outcome vulnerability approaches typically focus on biophysical changes in closed or at least well-defined systems. The boundaries between "nature" and "society" are quite firmly drawn and vulnerability is an outcome that can be quantified and measured. The outcome vulnerability is determined by the adaptive capacity of a system. However, regarding the adaptive capacity, most emphasis is given to biophysical components and the role of socio-economic components in modifying the effects of climate change is rather marginalized. Accordingly, the most vulnerable systems are considered to be those that will undergo the most dramatic physical changes.

Studies that follow an outcome approach typically focus on technological solutions for adaptation and mitigation strategies to minimize particular impacts of climate change (Brooks, 2003; Eriksen and Kelly, 2007; Füssel, 2007; O'Brien *et al.,* 2007). Studies that focus on the vulnerability of agricultural yields to climate change in the future tend to follow an outcome vulnerability approach and typical technological solutions for adaptation in the agricultural sector include, for example, the use of different crop seeds, production techniques or water management (Tubiello and Rosenzweig, 2008; Challinor *et al*., 2009; Peltonen-Sainio, 2012).

*Contextual vulnerability* (also known as the *"starting point" interpretation*) is a concept that considers vulnerability as the present inability of a system to cope with changing climate conditions, whereby vulnerability is seen to be influenced by changing biophysical conditions as well as dynamic social, economic, political, institutional and technological structures and processes. Thus, in the contextual approach, vulnerability is seen as a characteristic of ecological and social systems that is determined by multiple factors and processes (Adger, 2006; O'Brien *et al.,* 2007).

Based on social science, contextual vulnerability approaches typically focus more on the *current* socio-economic determinants or drivers of vulnerability, i.e. social, economic and institutional conditions. Specific determinants that can increase or decrease a system's vulnerability include, for example, marginalization, inequity, food and resource entitlements, presence and strength of institutions, economics and politics (Adger and Kelly, 1999; O'Brien and Leichenko, 2000; O'Brien *et al.,* 2004; Cardona *et al.,* 2012). Thus the contextual interpretation of vulnerability explicitly recognizes that vulnerability to climate change is not only a result of biophysical events alone but is also influenced by the contextual socio-economic conditions in which climate change occurs. Nature and society are usually seen as joint aspects of the same context, i.e. a strong human-environment interrelation is assumed and the boundaries between nature and society are not firmly drawn. The current vulnerability to climatic stimuli determines the adaptive capacity of a system, and climate change modifies not only the biophysical conditions but also the context in which climate change occurs.

The contextual approach builds on the dual consideration of socio-economic and biophysical aspects that make a system vulnerable (Turner *et al*., 2003; O'Brien *et al*., 2004; Polsky, Neff and Yarnall, 2007). The general concept of socio-economic vulnerability is illustrated in Schröter *et al.* (2005) with an example on famine. Schröter *et al.,* (2005) argue that rather than focusing on the physical stress (e.g. drought) as the cause of famine, it might be more informative to focus on the social, economic and political marginalization of the individuals or groups as the cause for that famine. Likewise, the contextual approach emphasizes that the social and ecological context in which climate change occurs is likely to be as important as the climatic shock itself (Bohle, Downing and Watts, 1994; Handmer, Dovers and Downing, 1999; Turner *et al*., 2003; Ericksen, 2008). This observation has been confirmed by quantitative research on agricultural production, such as quantitative work on the socio- economic factors that make grain harvests in China sensitive to rainfall anomalies (Fraser *et al.,* 2008; Simelton *et al*., 2009). Liverman (1990) demonstrated that different crop yields during drought periods in Mexico could not be solely explained by different precipitation patterns but were strongly influenced by different land tenure and the historical biases of farmers' access to productive resources. Likewise, Vásquez-Léon, West and Finan (2003) illustrated how differences in access to resources, state involvement, class and ethnicity result in significantly different vulnerabilities of farmers within a similar biophysical context. In an example for North America, Mendelsohn (2007) finds that about 39 percent of the variations in average crop failure rates across the United States of America can be explained by variations in soils and climate, which basically implies that other factors such as management skills, socio-economic, institutional and political conditions, account for the remaining 61 percent.

From the contextual interpretation, vulnerability can be reduced by modifying the contextual conditions in which climate change occurs so that individuals and groups are enabled to better adapt to changing climatic stimuli (Adger, 2006; Eakin and Luers, 2006; Eriksen and Kelly, 2007; O'Brien *et al*., 2007; Cardona *et al.,* 2012). Accordingly, studies that follow a contextual approach typically focus on sustainable development strategies that increase the response and adaptive capacity of human populations to deal with climate change-related vulnerabilities (thereby addressing the need for adaptation policy and of broader social development). An important feature of contextual approaches is typically the involvement of the population and stakeholders of the system in identifying climate-change stresses, impacts and adaptive strategies.

The alternative concepts and interpretations of vulnerability reflect the fact that vulnerability is context- and purpose-specific, and also specific to place and time as well as to the perspective of those assessing it (cf. Adger, 2006; Füssel and Klein, 2006; O'Brien *et al.,* 2007; Pearson and Langridge, 2008; IPCC, 2012). In practical terms, the question of "who is vulnerable to climate change?" can be addressed within both vulnerability approaches, with studies on outcome vulnerability focusing usually on vocations or professions, whereas contextual vulnerability focuses more on class, race, age or gender (O'Brien *et al.*, 2007). Outcome vulnerability approaches are also often associated with questions such as "what are the expected net impacts of climate change in different regions?" or "which sector is more vulnerable to climate change?" However, answering these questions may also form an important part of contextual approaches, especially if the economy of a society is dominated by activities that are sensitive to climate change (e.g. if the agricultural sector plays a vital role in a society's economy). Thus, the question "why are some regions or social groups more vulnerable than others?" is closely related to contextual approaches (O'Brien *et al.,* 2007).

As vulnerability is context- and purpose-specific, none of the vulnerability concepts can be considered as being better or worse than the other. As highlighted in O'Brien *et al.* (2007), the outcome and contextual interpretations of vulnerability should be recognized as being two complementary approaches to the climate change issue. The two approaches assess vulnerability from different perspectives and they are both important to understand the relevance of climate change and respective responses (Kelly and Adger, 2000; Adger, 2006; O'Brien *et al.*, 2007). Moreover, in recognizing that any complex system commonly involves multiple variables (physical, environmental, social, cultural and economic), it seems imperative to assess the vulnerability of a system by using an integrated or multidimensional approach in order to capture and understand the complete picture of vulnerability in the context of climate change (Cardona *et al.,* 2012).

In summary, and as delineated above, climate vulnerability is characterized as a function of both biophysical and socio-economic vulnerabilities, with each defined by the three dimensions of exposure, sensitivity and adaptive capacity. When combined with specific likelihood of occurrence (either associated with biophysical changes or socio-economic variables), climate vulnerability becomes climate risk (Preston and Stafford-Smith, 2009). The relationship among different concepts associated with climate change vulnerability and risk are graphically depicted in Figure 5.

## 4. THE TIME DIMENSION: FURTHER CHARACTERIZATION OF CURRENT AND FUTURE VULNERABILITY

The discussion on alternative interpretations of vulnerability highlights that there are two different temporal references (time horizons) for assessing vulnerability. While the conceptualization of outcome vulnerability focuses on future vulnerability, contextual vulnerability focuses on current vulnerability. This distinction can mostly be attributed to the different disciplines that are involved in research on vulnerability and adaptation (Preston

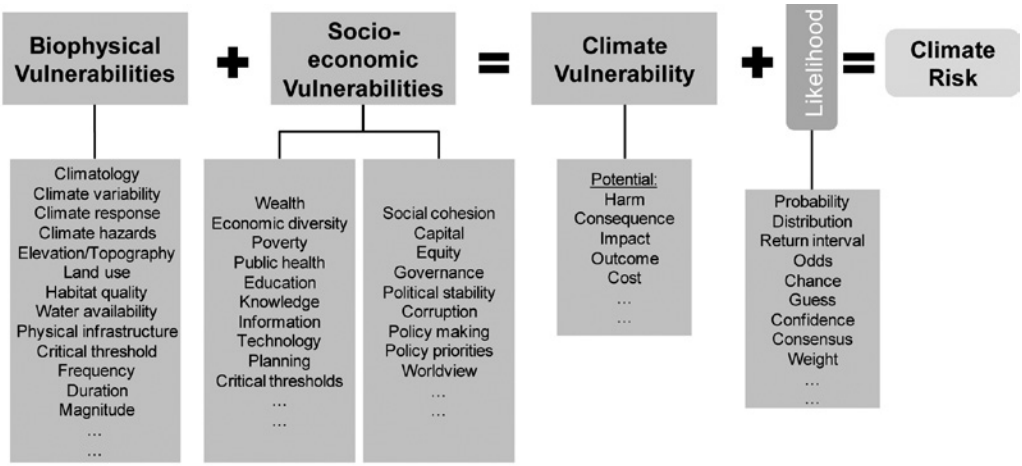

**Figure 5. Relationship among different concepts associated with climate vulnerability and risk**
*Source*: Modified from Preston and Stafford-Smith (2009).

and Stafford-Smith, 2009; cf. section above). As described above, natural scientists usually focus on biophysical determinants of climate change and thus assess future vulnerability as the end-point of the analysis. On the other hand, scientists focusing on socio-economic determinants tend to focus on current vulnerability as the starting-point of the analysis.

Preston and Stafford-Smith (2009) point out that both timeframes are important and valid and that it may be useful to maintain these different perspectives. However, non-climatic (socio-economic) factors can strongly modify the climatic impacts of climate change (Carter *et al*., 2007; Polsky, Neff and Yarnall, 2007), which implies that future vulnerability also critically depends on present (autonomous and/or planned) adaptation processes (Downing and Patwardhan, 2005; Carter *et al.,* 2007, Carter and Mäkinen, 2011). Consequently, to obtain a complete picture of vulnerability it seems necessary to combine both the two time horizons (current and future) and biophysical and socio-economic vulnerability determinants. Preston and Stafford-Smith (2009) depict the relationship between current and future vulnerability to climate change in a diagram, with both temporal references comprising biophysical as well as socio-economic determinants (Figure 6).

## 5. METHODS FOR ASSESSING VULNERABILITY TO CLIMATE CHANGE

The diversity of interpretations and concepts of vulnerability results in a variety of methodological approaches and tools that have evolved to assess it, which is also reflected in a vast variety of conducted vulnerability assessments with regard to the agricultural sector. Climate change vulnerability assessments can, for example, vary with respect to the methodological approach (e.g. experimental, modelling, meta-analysis, survey-based), the integration of natural and social science, policy focus, time horizon (short- to long-term), spatial scale (farm, local, national, regional, global level), consideration of uncertainties, and the degree of stakeholder involvement. In this section, general methods applied for assessing vulnerability to climate change are highlighted, focusing briefly on the use of indicators, modelling approaches and stakeholder involvement. Thus, the methods out-

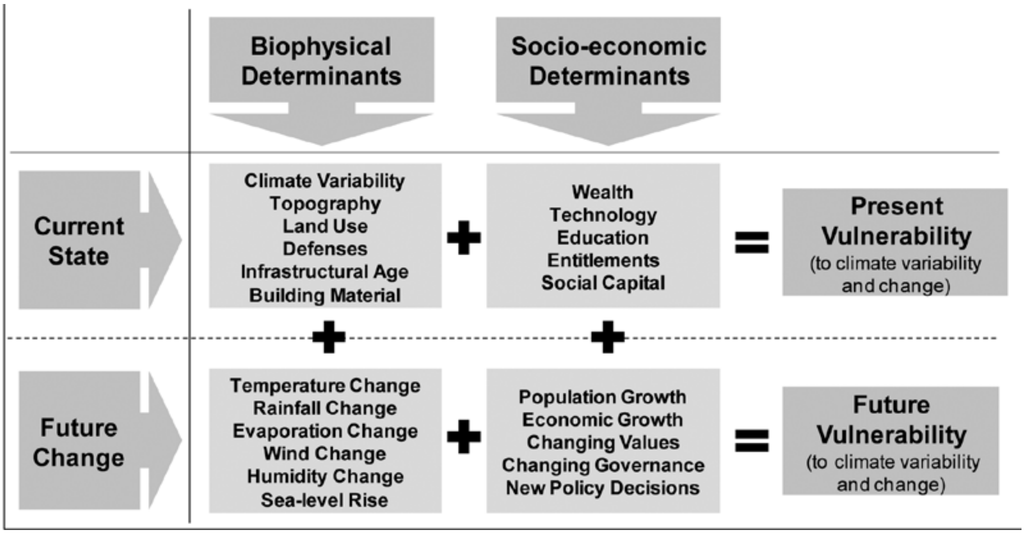

**Figure 6. Relationships between current and future determinants of vulnerability to climate variability and change**
*Source*: Slightly modified from Preston and Stafford-Smith (2009).

lined in these sections are illustrative rather than exhaustive.

The methods used in vulnerability assessments tend to be closely related to the concept and interpretation of vulnerability. In line with the outcome and contextual interpretations of vulnerability, Dessai and Hulme (2004) highlight the different approaches that the two concepts take (without explicitly referring to them) to inform climate adaptation policy. Figure 7 illustrates that outcome vulnerability concepts that concentrate on physical vulnerability tend to follow a top-down approach to inform climate adaptation policy, whereas contextual vulnerability concepts that concentrate on socio-economic vulnerability follow a bottom-up approach (Dessai and Hulme, 2004; cf. IPCC-TGICA, 2007). A top-down approach typically proceeds from global climate projections, which can be downscaled and applied to assess regional impacts of climate change. An important feature of bottom-up approaches is typically the involvement of the population and stakeholders of the system in identifying climate-change stresses, impacts and adaptive strategies.

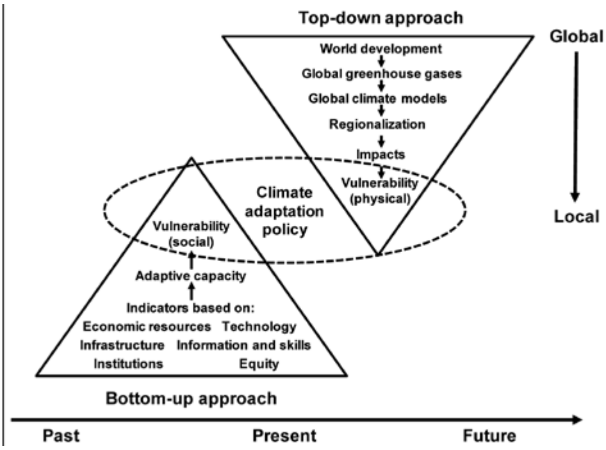

**Figure 7. Top-down and bottom-up approaches to inform climate adaptation policy**
*Source*: Dessai and Hulme (2004).

### *Vulnerability indicators and indices: to be used with caution*

A common method to quantify vulnerability to climate change is by using a set or composite of proxy indicators. Indicators can, for example, be used to link biophysical and economic attributes of systems to vulnerability outcomes via a quantitative function (e.g. decline in yield, resource quality, land value or economic returns). However, identifying and constructing appropriate indicators for vulnerability assessments is highly challenging (Downing *et al*., 2001; OECD, 2008). Following the IPCC definition of vulnerability to climate change, measures of vulnerability typically include the three components of climate change, i.e. exposure to climate change, sensitivity to its effects, and adaptive capacity to cope with the effects. Vulnerability assessments, therefore, typically attempt to quantify the three components by identifying appropriate indicators and combining them into indices for each. Subsequently, the components are then often combined into an integrated index of vulnerability. The indicators used for the components include usually both biophysical (primarily for exposure and sensitivity) and socio-economic (mainly for adaptive capacity) sources (Yohe and Tol, 2002; Adger *et al*., 2004; Schröter *et al.,* 2005; Metzger and Schröter, 2005; Eakin and Luers, 2006; Gbetibouo, Ringler and Hassan, 2010; cf. Iglesias, Quiroga and Diz, 2011).

Impacts of climate variability and change can generally be described quantitatively by changes in biophysical indicators (e.g. agricultural productivity with regard to crop yields) or by socio-economic indicators (e.g. agricultural income from crop production). However, while there are agreed indicators to measure the *impact* of climate change, there seem to exist no agreed metrics to describe *vulnerability* (e.g. of crop yields or agricultural income). This seems to be the case because vulnerability is rather a relative measure than something that can be expressed in absolute terms (Adger, 2006; Füssel and Klein, 2006; Eriksen and Kelly, 2007; Füssel, 2009; Hinkel, 2011). Consequently it is argued, that: (i) an indicator can generally only describe a measure of relative vulnerability (between places or time periods); and (ii) individual indicators are not able to portray the heterogeneity of vulnerability (especially with regard to socio-economic vulnerability). Hinkel (2011) therefore argues that a "one size fits all" vulnerability label is not sufficient as it disguises the vast amount of different types of problems addressed and methods applied. Thus, rather than using the term vulnerability as an unspecific proxy, it is important to use an explicit terminology in order to clarify which particular vulnerability problems are addressed and which methodologies are applied (Füssel, 2009; Klein, 2009; Hinkel, 2011).

As discussed in previous sections, vulnerability is place-based and context-specific and consequently the significance of particular indicators can vary from region to region, especially depending on the specific socio-economic context. Consequently, at local scales and when systems can be narrowly defined, vulnerability indicators are considered to be a suitable means to identify particularly vulnerable people, regions or sectors (Barnett, Lambert and Fry, 2008; Hinkel, 2011). Conversely, attempts to rank and compare vulnerability across regions or countries via indicator values, mainly with the aim to assist governmental bodies or organizations in the allocation of resources to reduce vulnerability, are often criticized. The criticism of ranking and comparing vulnerability across countries arises mainly because vulnerability is place- and context-specific, but also because of challenges owing to quality and availability of data, the selection and creation of appropriate indicators, underlying assumptions in weighting variables, and the interpretation of indices. Moreover, the dynamic nature of vulnerability would actually require a constant updating of such vulnerability scores (Cutter, Boroff and Shirley, 2003; Eakin and Luers, 2006; Füssel, 2009; Klein, 2009; Hinkel, 2011).

### *Model-based vulnerability and impact assessments*

Research of climate change-related vulnerability and impact in the agricultural sector mainly focuses still on biophysical productivity. Most of the models used follow reductionist approaches, focusing on a single or well-defined group of hazards or drivers of change. Biophysical model approaches typically following a dose-response logic, focus on biophysical processes and are limited in the integration of contextual issues. Thus, these model approaches have limited capacity to model adaptation options (however, some rather predefined contextual adaption can be considered). Pure biophysical model approaches can range in their complexity, from using only one single climate variable and one single response to the incorporation of many processes that are considered as being important in determining system responses (e.g. dynamic vegetation models). Biophysical model approaches in the agricultural sector can assess, for example, the suitability of specific crops as a result of change in climate (e.g. Peltonen-Sainio *et al*., 2009), and can be used to forecast (e.g. Olesen *et al*., 2007) or simulate (e.g. Palosuo *et al*., 2011) changes in yields.

A common approach to model socio-economic vulnerability and impacts is to combine biophysical models (or their outcome) with economic simulation models in order to assess impacts of climate change on agricultural productivity and related costs of adaptation (see, for example, Nelson *et al*., 2009; Reidsma *et al*., 2010). Alternatives to such simulation approaches are statistical approaches. Statistical approaches can, for example, be applied to estimate statistical relationships between crop yields, temperature and precipitation (see, for example, Schlenker and Lobell, 2010). Statistical studies can also be based on cross-sectional data or time-series data. In general, statistical approaches have the advantage that they require less data than simulation issues, such as, for example, changes in varieties grown not taken into account), i.e. no adaptation responses are considered. In contrast, adaptation responses are somehow considered in Ricardian approaches. Ricardian approaches recognize that farmers will vary their mix of activities (to yield the highest return on their land) and therefore they focus on the impact of climate change on land values instead of yields. Thus, in Ricardian approaches, climatic variations are associated with variations in land values in order to estimate the economic impact of changes in climate once adaptation has taken place. Critique on Ricardian approaches arises because they rely on the assumptions that there is a long-run equilibrium in factor markets (especially land) and that there are no adjustment costs. Furthermore they are comparatively static, i.e. dynamics of adjustments are not considered (see, for example, Mendelsohn *et al*., 2007; Mendelsohn, 2008; Lippert, Krimly and Aurbacher, 2009).

### *Stakeholder involvement*

Especially at local and national scales, the application of vulnerability assessment methods allows interaction with stakeholders. The involvement of stakeholders can take place at several stages of an assessment to agree upon the main issues and responses in assessing vulnerability to climate change. Participatory methods are applied in order to obtain first-hand documentation of vulnerability owing to social conditions and physical stimuli from the perspectives of community members. Furthermore, when quantitative data are not available, expert opinions of regional stakeholders can offer alternative sources of information. In addition, stakeholders can also provide valuable information on non-climatic stimuli that may be important for mitigating climate change impacts (Downing and Ziervogel, 2004; Salter, Robinson and Wiek, 2010; Malone and Engle, 2011).

There are various methods to involve stakeholders, including cognitive mapping, expert judgement, brainstorming or checklists, but also via interviews or surveys (for brief descriptions, see Downing and Ziervogel, 2004). Participatory stakeholder methods can generally help to produce results that are more acceptable to stakeholders and therefore also more implementable. The involvement of stakeholders is considered as being particularly crucial in identifying and planning the most appropriate forms of adaptation (which will then also contribute to a successful implementing of adaptation policies). The level of stakeholder involvement can vary from passive engagement (providing information through meetings or interviews) to self-mobilization (initiating and designing processes). Generally, stakeholder involvement can be used as the main method for vulnerability and adaptation assessments as well as in combination with other methods (Downing and Ziervogel, 2004; Salter, Robinson and Wiek, 2010; Malone and Engle, 2011).

As highlighted in the previous sections of this paper, vulnerability is context- and purpose-specific and hence the answer to the question which vulnerability assessment approach for the agricultural sector, production system and/or region is most appropriate depends on multiple aspects, among others the specific research or policy questions to be addressed, the geographical and temporal scope of the analysis, and the availability of data, expertise, and other resources.

## 6. DATA CONSTRAINTS AND TREATMENT OF UNCERTAINTIES

Questions related to the availability, quality and application of information and data as well as related uncertainties are important and should be addressed in any vulnerability assessment. There is vast literature on the use of data and scenarios in climate change impact and vulnerability assessments (e.g. Carter *et al.*, 2007; IPCC-TGICA, 2007; Rounsevell and Metzger, 2010) and, for example, the Data Distribution Centre (DDC) of the IPCC provides climate, socio-economic and environmental data, along with technical guidelines on the selection and use of different types of data and scenarios (IPCC-DCC, 2012).

Climate change impact and vulnerability assessments apparently contain a certain level of uncertainty and it is necessary to document and communicate the uncertainties associated with the choice and availability of data, the approach taken and the results of the assessment (IAC, 2010; Mastrandrea *et al.,* 2010; Jones and Preston, 2011). Moss and Schneider (2000) highlight several examples of sources of uncertainties, comprising: (i) problems with data (e.g. missing, errors, noise, random sampling error and biases); (ii) problems with models (e.g. structure, parameters, their credibility over time, predictability of the system or effect, approximation techniques); and (iii) other sources of uncertainty (e.g. ambiguous definitions of concepts and terminology, inappropriate spatial/temporal units, underlying assumptions, human behaviour in the future).

Some categories of uncertainty are possible to quantify, while others cannot be sensibly expressed in terms of probabilities. In the guidelines for the Fifth Assessment Report of the IPCC, two metrics for the communication of the degree of certainty are proposed, with one metric comprising quantified measures of uncertainty in a finding that can be expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment). The other metric for the degree of certainty is expressed qualitatively and comprises confidence in the validity of a finding, based on the type, amount, quality,and consistency of evidence (e.g. mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement (Mastrandrea *et al.*, 2010).

In any vulnerability assessment, the data and methods applied to characterize the past, present and future in the assessment (e.g. for climate, other environmental, land use, socio-economic and technological conditions) should be clearly stated. Likewise, it has to be communicated which parts of the assessment are based on observations, on models and on future scenarios. Data constraints (e.g. availability, quality, applicability) need to be indicated and for the communication of uncertainties in a vulnerability analysis it is useful that the most important factors and uncertainties that are likely to affect the conclusions are identified for each of the major findings (Moss and Schneider, 2000; Swart *et al.*, 2009; Mastrandrea *et al.*, 2010).

## 7. CONCLUDING REMARKS AND FRAMEWORK TABLE FOR CLIMATE CHANGE-RELATED VULNERABILITY ASSESSMENTS

OECD and FAO are working together on an analytical report that focuses on building resilience in agricultural production systems in the context of climate change. In the context of the report, the purpose of this paper is to provide a review of conceptual frameworks for the assessment of climate change-related vulnerability, highlight major differences in alternative vulnerability interpretations and give some reference examples for the agricultural sector. In the literature, many authors recognize the potential linkage between vulnerability and resilience (e.g. Turner *et al.*, 2003; Eakin and Luers, 2006; Gallopin, 2006; Young *et al.*, 2006; Nelson, Adger and Brown, 2007; Polsky, Neff and Yarnall, 2007; Vogel *et al.*, 2007; Cutter *et al.*, 2008; Turner, 2010; Engle, 2011). Even though vulnerability and resilience can be seen as separate concepts, they are linked through the concept of adaptive capacity (Engle, 2011; see Figure 8) and greater emphasis from a combined perspective can help to assess adaptive capacity (Engle, 2011).

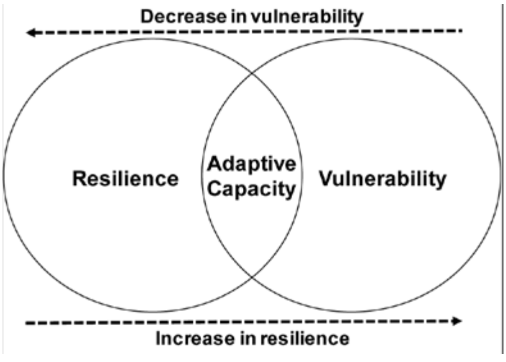

**Figure 8. Vulnerability and resilience frameworks as linked through the concept of adaptive capacity**
*Source*: Adjusted from Engle (2011).

Assessments in the climate change area are usually characterized by collaboration

**Table 1: Alternative concepts and interpretations of vulnerability in climate change research**

| | **Outcome vulnerability (end-point interpretation)** | **Contextual vulnerability (starting-point interpretation)** |
|---|---|---|
| Root problem | Climate change | Socio-economic vulnerability |
| System of interest | Biophysical, closed or at least well-defined systems | Human security or livelihood interrogation |
| Main discipline | Natural science | Social science |
| Analytical function | Descriptive, positive | Exploratory, normative |
| Starting point of analysis | Scenarios of future climate change | Current vulnerability to climatic stimuli |
| Vulnerability and adaptive capacity | Adaptive capacity determines vulnerability | Vulnerability determines adaptive capacity |
| Reference for adaptive capacity | Adaptation to future climate change | Adaptation to current climate variability |
| Meaning of vulnerability | Expected net damage for a given level of global climate change | Susceptibility to climate change and variability as determined by socio-economic factors |
| Illustrative research question | What are the expected net impacts of climate change in different regions? | Why are some groups more affected by climatic hazards than others?<br>Who is vulnerable to climate change and why? |
| Policy context | Climate change mitigation, compensation, technical adaptation | Social adaptation, sustainable development |
| Illustrative policy question | What are the benefits of climate change mitigation? | How can the vulnerability of societies to climatic hazards be reduced? |
| Focus of results | Technologically focused on adaptation and mitigation strategies | Socially focused on increasing adaptive capacity, exploring alternative development pathways, addressing power or equity issues and constraints to respond |
| Approach used to inform adaptation policy | Top-down approach | Bottom-up approach |
| Spatial domain | Global -> local | Local -> regional |
| Time dimension | Future vulnerability | Current vulnerability |

*Source*: Modified from Füssel (2007) and Pearson *et al.* (2008).

of researchers and stakeholders with different backgrounds and knowledge. Different interpretations of the character and cause of vulnerability can result in different accentuations of strategies for reducing vulnerability. Therefore, it is important to identify the thinking behind specific vulnerability concepts and highlight the major differences in alternative vulnerability interpretations. Two of the most prominent vulnerability concepts in the context of climate change are outcome (end-point) and contextual (starting-point) vulnerability. The main features and differences between the outcome and contextual vulnerability approaches of vulnerability are summarized in Table 1.

While both concepts define the vulnerability of a system to climate change as a function of exposure, sensitivity and adaptive capacity of the system, the major differences are mainly attributable to the relative role of natural and social science within the outcome and contextual concepts. Outcome approaches are usually based on natural science and focus on future biophysical changes. Regarding adaptive capacity, most emphasis is given to biophysical components, and the role of socio-economic components in modifying the effects of climate change is rather marginalized. In contrast, contextual approaches are based on social science and consider vulnerability as the present inability of a system to cope with changing climate conditions. Contextual vulnerability approaches typically focus more on the current socio-economic determinants or drivers of vulnerability, i.e. social, economic and institutional conditions.

The alternative concepts of vulnerability reflect the fact that vulnerability is context and purpose specific, and also specific to place and time as well as to the perspective of those assessing it. The outcome and contextual concepts of vulnerability should be recognized as being two complementary approaches to the climate change issue, assessing vulnerability from different perspectives and both being important to understand the relevance of climate change and respective responses. Moreover, as any complex system commonly involves multiple variables (physical, environmental, social, cultural and economic), it seems important to assess the vulnerability of a system by using an integrated or multidimensional approach in order to capture and understand the complete picture of vulnerability in the context of climate change.

Similarly to the alternative concepts of vulnerability, the answer to the question which vulnerability assessment approach for the agricultural sector, production system and/or region is most appropriate depends on multiple aspects. Among these are specific research or policy questions to be addressed, the geographical and temporal scope of the analysis, and the availability of data, expertise and other resources. In general, vulnerability assessments should help to identify the impacts of climate change at sectoral, global, national or local level and help to raise awareness and identify key issues. Thus, an assessment of agricultural vulnerability to climate change should help to identify particularly vulnerable regions and agricultural production systems. This should then result in recommendations of specific adaptation measures and also help to prioritize resource allocation for adaptation. Accordingly, vulnerability assessments should be aimed at informing affected stakeholders (farmers, policy-makers, etc.) and the development of response options (adaptation techniques, policies, etc.) that reduce risks associated with climate change.

To operationalize the issues outlined in this paper, Table 2 presents a framework table, including the main elements that are considered relevant for the assessments of climate change-related vulnerability in the agricultural sector. The framework table could be a useful reference for those actually doing the vulnerability assessment, as well as for stakeholders, policy-makers and further users of the respective vulnerability analysis. The table can be helpful in presenting main elements of a vulnerability analysis by reducing complexity and thus easing comparison, understanding and communication of approaches and results of vulnerability assessments.

**Table 2: Elements of a framework for climate change-related vulnerability assessments in the agricultural sector**

| **Assessment type, purpose and target audience** | |
|---|---|
| Study name | Full name |
| Specific research questions | Indicate the specific research questions addressed by the analysis |
| Emphasis and approach of the assessment | Main orientation (climate risks, adaptation, global policy analysis) and main approach (vulnerability, but could be also impact, adaptation, integrated) |
| Target audience | The intended target audience and other potential interested parties (e.g. researchers, policy-makers, affected farmers, communities, other stakeholders) |
| **Dimensions of the assessment** | |
| System of interest (sectoral/ thematic focus) | Thematic focus of the assessment (agricultural productivity, food security, water resources, rural livelihood, etc.). Indicate if other sectors than agriculture (specific population groups or communities, etc ) are considered |
| Regional scope | Region(s) for which the analysis is carried out and results are valid |
| Spatial scale | Spatial scale of the analysis (farm, local, national, regional, global level) for which the analysis is carried out and results are valid |
| Temporal reference | Indicate if the focus is on current and/or future vulnerability. Indicate if past, current and/or future perspectives are included in the analysis |
| Biophysical aspects considered | Indicate the biophysical aspects considered in the analysis |
| Socio-economic aspects considered | Indicate the socio-economic aspects considered in the analysis |
| **Methods and participation** | |
| Methods and tools | Specific analytical methods and tools applied in the assessment as well as details of their application |
| Involvement of stakeholders | Yes/No (in the case of yes, indicate key stakeholder groups who have formally contributed to the assessment and the format of their involvement) |
| **Information management** | |
| Data and scenarios | Data and methods applied to characterize the past, present and future in an assessment (e.g. for climate, other environmental, land-use, socio-economic and technological conditions) |
| Data constraints | Indicate data constrains (e.g. availability, quality, applicability) |
| Treatment of uncertainty | Sources of uncertainty (due to e.g. problems with data, models, underlying assumptions) and their treatment |
| **Assessment outputs** | |
| Metric(s) | Specific measures/measurements and units in terms of which results are presented (e.g. change in crop yields, farm income, or indicators) |
| Presentation of results | Approach for displaying and documenting results, background information, methods and conclusions to users (use of narratives, maps, charts, tables) |
| Documentation and publications | Peer-reviewed articles, technical reports, other reports, web descriptions, etc. |

*Source*: Adapted from a proposed framework by Carter and Mäkinen (2011).

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# Climate change and animal health

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## INTRODUCTION

Systematic reviews of empirical studies provide the best evidence for the relationships between the health of humans, animals and plants, and weather or climate factors. Regarding the public health sector, Chapter 8 of the Working Group II report of the Intergovernmental Panel on Climate Change (IPCC) for 2007 comprises an update on the state of knowledge of the associations between weather/climatic factors and public health outcomes for human populations concerned (Patz *et al.,* 2005). Direct exposure to climate change comprises changing weather patterns (increasing temperatures, more precipitation, rising sea-level and more frequent extreme events). Indirect exposure comprises changes in water, air and food quality, vector ecology and changes in ecosystems, agriculture, industry and settlements. Additional indirect exposure may result from social and economic disruption. Possibilities for adaptation extend to concurrent direct-acting and modifying (conditioning) influences of environmental, social and health system factors. How critical global warming could become a threat to public health has been studied for several risk settings, comprising malaria, water shortage, famines and coastal flooding. Water shortage is often associated with unsanitary water conditions and therefore with a major impact of climate change on health, for example, through diarrhoeal disease.

Unfortunately, in the animal health realms, comprehensive, formal reviews are rare (de la Rocque, Rioux and Slingenbergh, 2008). Climate change and general anthropogenic factors together alter both the farming and the natural landscapes and in the process impact the health of animals in multiple ways. This paper is primarily concerned with the effects of climate change on disease ecology and transmission dynamics. Importantly, changes in host distribution, density and their availability to existing pathogens may translate in disease emergence in animals and at the animal-human interface. A pathogen may: (i) find access to new territories and host landscapes; or (ii) turn more host aggressive in settings where the hosts have become more abundant and/or immune-compromised; or (iii) perform a host species jump, possibly in response to enhance host species mixing or contacts. Geographic spread or invasion may entail a range expansion or, in case of saltation dispersal, kick-start a complete pathogen genetic remake (see Figure 1). The disease emergence category featuring an expansion of the geographic range is both relatively common and also more likely

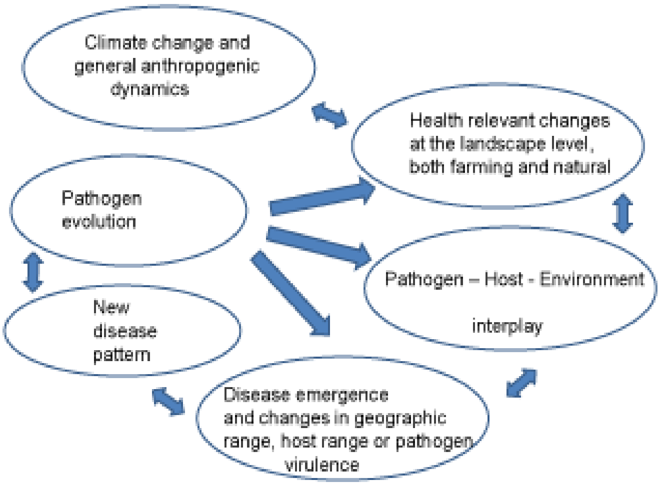

**Figure 1. Effects of climate change on disease emergence**

to be affected by climate change, and for this reason is the main focus of this paper. This group of disease complexes comprises insect pests, ecto-parasites, endo-parasites, arthropod-borne disease complexes and pathogens carried by foods and fomites. A set of global factors is believed to drive a worldwide redistribution of hosts, vectors and pathogens. Climate change clearly plays a role in this regard, enhancing or decreasing the introduction and invasions of disease agents, even when primarily caused by other factors such as the demography of humans and animals, encroachment of the natural resource base, land use, agriculture, the greater mobility of people, and the enhanced trade and traffic volumes. When it comes to the role of climate change in disease ecology and pathogen evolution, there is a need to duly consider the collective host–pathogen–environment interplay. In a stable environment, a situation of relative evolutionary stasis, host–pathogen–environment complexes tend to become more entrenched, with location-bound pathogen traits selected for. Conversely, in a rapidly changing environment, it is pathogen opportunism and generalist type versatility that matters.

## CLIMATE CHANGE AND TRANSMISSION ECOLOGY

From a climate change perspective, it is important to assess the extent to which a pathogenic agent is exposed to the conditions outside the host body. A free-living pathogen stage plays a role even in the direct transmission of respiratory diseases. The survival of the common flu virus on doorknobs or during aero-gene transmission or by means of handshakes is influenced by ambient temperature and humidity (Lowen *et al.*, 2007). The role of environmental pathogen load is perhaps more obvious still in the case of faecal-oral or water-borne transmission. Food poisoning usually entails faecal contamination of food items. Environmental robustness is a prominent feature in certain stages of the life history of larger parasites, including in nematodes, with larvae surviving for weeks or more outside the host on pastures. The natural cycle of avian influenza viruses in mallard ducks, its foremost natural host, involves ingestion of water containing the virus. Natural avian influenza virus replication occurs mainly in the distal end of the enteric duck tract (Jourdain *et al.,* 2010). Viruses deposited by migratory waterfowl during summer breeding at higher latitudes may be stored in permafrost conditions in subarctic regions and survive for centuries (Zhang *et al*., 2006). Likewise does the anaerobe *Bacillus anthrax* bacterium survive for decades in the form of spores in the soil (Dragon and Rennie, 1995).

Disease agents transmitted by arthropods form a distinct, albeit related category. Indirect transmission of protozoan disease agents may be facilitated by three-host ticks. Soft ticks feeding on warthogs play a role in the transmission of African swine fever (ASF) (Kleiboeker and Scoles, 2001). The causative agent of ASF, a DNA virus, may survive for eight years in the tick vector. There are also a number of midge- or mosquito-borne disease complexes that involve a dormant pathogen stage. For example, Rift Valley fever (RVF) virus may survive in mosquito eggs for years, until a prolonged heavy rainfall facilitates an awakening of *Aedes* mosquitoes, feeding on ruminants and thus kick-starting a RVF outbreak (Mondet *et al*., 2005; Anyamba *et al*., 2009). Infected ruminants that end up in densely populated irrigation schemes may also attract mosquitoes feeding on humans and thus contribute to the transmission of RVF among humans.

Midges are sometimes blown by wind across wider geographic areas. This is probably what happened with bluetongue virus (BTV8) introduction in the United Kingdom, in the summer of 2006, after the virus had first spread westwards across Belgium (Gloster *et al.,* 2008). It is very possible that also the flare up of the Schmallenberg virus (SBV) in the United Kingdom in early 2012 resulted from wind-carried infected midges arriving from mainland Europe (Gibbens, 2012).

In the direct-indirect transmission spectrum, directly, swiftly transmitted common flu, short-lived fevers, faecal–oral, food and vector-borne transmission to more prominent free-living parasite stage can be noted. In this regard, ecto-parasites and myiasis-causing insects should also be considered. Arthropod pests are strongly modulated by climatic and weather conditions. For example, both the Old World screwworm fly (OWS), *Chrysomya bezziana*, and the New World screwworm fly, *Cochliomyia hominivorax*, feature a prominent free-living stage. The adult female fly deposits eggs in open wounds and also minor skin lesions or on mucous membranes, providing access for the evolving larval stages to life tissue of warm blooded hosts (Spradbery, 1991). The latter is obligatory for this life cycle stage. Hundreds of larvae may result from a single egg batch, producing an ever-larger wound. Additional screwworm flies are lured to the scene, and death of the affected host may eventually result. The larvae leaving the wound fall to the soil and bury themselves 2 cm deep, to turn into a pupa for about a period of one week until a new fly emerges. Adult flies feed on nectar and rely on adequate vegetation.

As shown in Figure 2, substantial areas of the Arabian Peninsula today provide suitable conditions for OWS persistence. OWS flare-up in the Gulf countries has been reported since the 1980s. Apart from rather small foci in Oman, Saudi Arabia and Iran, OWS myiasis did not pose a serious problem to livestock production until a major outbreak erupted in the mid-1990s in Iraq. As a result of the United Nations sanctions, the country ran out of acaracide supplies required to keep the sheep flocks free from ticks. With the higher number of skin lesions, also the vulnerability to OWS incursions increased. An FAO study predicted OWS suitability across the Arabian Peninsula on the basis of satellite-derived proxies for soil temperature and presence of vegetation. The results suggested Yemen as a potential area where OWS might flare-up and turn endemic. Indeed, large areas of southwestern Yemen have turned OWS endemic during the 2000s, with ever prominent, mostly springtime, disease outbreaks.

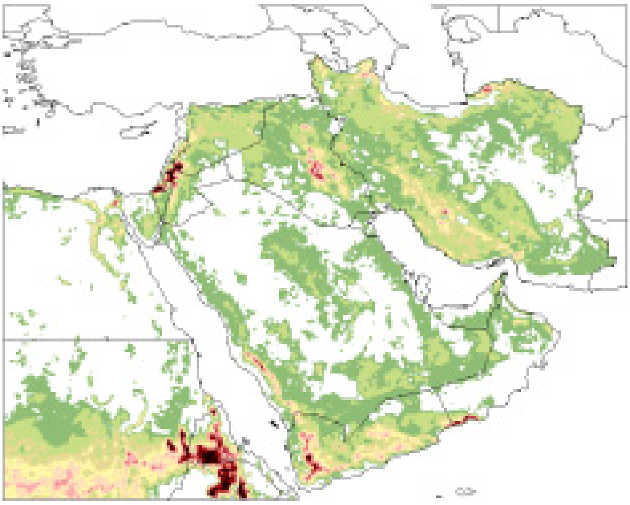

**Figure 2. Areas where the risk of Old World screwworm is relatively high (dark shade)**
*Source*: Gilbert and Slingenbergh (2008).

The effects of climate change on tsetse flies, the vector of human and animal African trypanosomiases, is rather different, despite certain similarities between the tsetse and the screwworm fly life history. The tsetse fly also features a pupal stage in the soil. However, whereas a single screwworm fly egg batch may yield over 200 larvae, the female tsetse fly produces only one larva every nine days. During its total lifespan, a female tsetse fly may produce six to eight larvae, each of which undergo a pupal development period of about three weeks depending on ambient temperatures (Ford, 1971). Unlike screwworm flies, dispersing over hundreds of kilometres within weeks, tsetse flies sit and wait for the host to show up. Tsetse fly activity is restricted to 15 to 20 minutes a day.

From the above examples, it becomes clear that the effects of climate change on disease complexes may take many different forms, complicating comparison and generalization. Whereas the tsetse fly distribution in Ethiopia entails a gradual encroachment of the country's central highland plateau (Slingenbergh, 1992.), recorded since the 1960s, the Old World Screwworm fly rather abruptly colonized the Arabian peninsula, first the Mesopotamia valley in Iraq and later parts of Yemen, within the course of just two decades (Siddig *et al.*, 2005).

A disease complex may also change the transmission mode or pattern. For example, ASF virus circulates in the form of at least 22 different genotypes in its sylvatic cycle – the warthogs as distributed in the miombo woodlands of southern Africa. Yet, in 2007, genotype II found its way to central Europe, starting in Georgia, in a Black Sea port. It is believed that meat products containing ASF virus were shipped from Mozambique or Madagascar and disposed of in Georgia as food scraps and fed to local pigs. Today ASF is progressively colonizing higher latitude areas of eastern Europe, propagated by people transporting contaminated pig meat products, through pig production, and also involving the Eurasian wild boar, *Sus scrofa.*

## RESILIENCE IN ANIMAL HEALTH

Basically, there are three distinct entry points that may lead to a better way of coping with the negative consequences of climate change and associated drivers of disease, pest dynamics and the overall health status of animals.

### Preventive veterinary medicine

As has been shown by the FAO Emergency Prevention System (EMPRES), since its creation in 1994, early warning, early detection, and early response have been key to the prevention and control of both old and new pests and diseases in animal and crop production. Prevention and curtailing the spread of disease across country boundaries has become the credo of the FAO/World Organisation for Animal Health (OIE) initiative, Global Framework for the Progressive Control of Transboundary Animal Diseases (GF-TAD). Progressive control pathways and regional roadmaps are being designed to counter the spread of high-impact infectious livestock diseases such as foot-and-mouth disease (FMD), peste des petits ruminants (PPR) and ASF.

Early detection and early response were also key to the success of the Global Rinderpest Eradication Programme. Following years of vaccination of the entire national cattle herd, countries gradually replaced the blanket vaccination by early detection and early response, in the process consolidating and expanding the rinderpest-free areas. In mid-2011 both OIE and FAO proclaimed the world free from rinderpest.

Yet the flare-up of new disease and the persistence of chronic disease burden remain considerable, particularly in the developing world. Climate change-modulated vector-borne disease (VBD) complexes would appear to become more dynamic globally, especially in the temperate climate zones of the northern hemisphere. In many countries, the expertise in entomology and disease ecology within public veterinary services is inadequate to mount early warning and response mechanisms in the face of novel VBD emergencies. Improvements are required also in terms of a further integration of field veterinary work, laboratories and detection of critical control points further along the food chain.

A “One Health” approach conveniently deals with the collective risk factors acting at the level of natural and farming landscapes, on-farm, in slaughterhouses and processing and distribution circuits. “One Health” brings together health professionals engaged as veterinary practitioners and food inspectors, working in fisheries health, forestry, plant protection, natural resource management and, of course, food safety and public health.

Removing the divides separating today disciplines, sectors, institutions and political boundaries, undoing the compartmentalization as prevailing in government organizational structures, presents the major challenge under the “One Health” umbrella. For FAO, the “One Health” notion extends to the Food Chain Crisis Management Framework, a platform for all health professionals within the Organization (Figure 3) (Tekola *et al.,* 2012).

### Adjustment of animal husbandry

Improvement in sanitation, hygiene or biosecurity may conveniently take a whole-of-society approach. Risk factors vary with animal production subsectors and systems. The management of animal genetic resources, feeding practices, housing and bio-containment

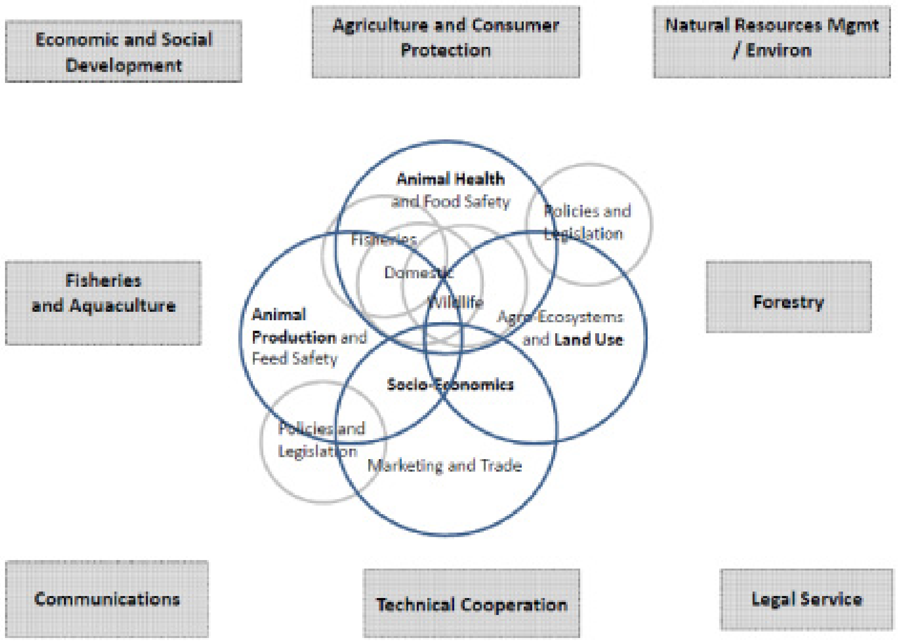

**Figure 3. FAO Departments (rectangles) and intersecting thematic areas of work**

together play a key role in the maintenance of robust, healthy and productive animals. Agro-ecological resilience matters most where production environments reflect the local conditions. Local breeds may harbour genetic disease resistance and other traits reflecting their adjustment to the locally prevailing conditions.

Ruminant grazing in the open brings exposure to multiple arthropod-borne diseases. A growing armoury of quality vaccines is required to confront a vast array of old and new diseases. Vaccination is particularly a priority in developing countries. Disease flare-ups at the human-animal-ecosystems interfaces are particularly prominent in pig and poultry production, with Influenza A as a primary example. A number of new emerging diseases, in part climate change modulated, are finding their way from wildlife reservoirs via pigs to humans. Fruit bats may transmit Henipah viruses (HeV) or Reston Ebola virus (REBOV). The management of this growing number of veterinary and medical threats requires adjustment of natural resource management practices, land use and food and agriculture. Safe and healthy food and agriculture requires re-definition.

## Social resilience

Empowering the community regarding health protection presents the key priority. With health systems and infrastructures being weakest in remote rural areas and harsh environments where ruminant livestock production is the most prominent among the prevailing farming systems, self-help options supported by community animal health outreach are rapidly gaining in importance. This extends to participatory disease surveillance and control, relying also on syndromic surveillance. Where vaccination is integrated with adjustments in husbandry and increased off-take results, prospects evolve for sustainable improvements in food and income security, in turn paving the way for an upgrading of the livestock production and farming systems in settings today featuring major disease burdens and low levels of productivity.

As the experience with rinderpest eradication has shown, community-based health protection efforts stand a good chance of success provided livelihood sustenance is made both the entry point and the ultimate rationale for the collective stakeholder efforts.

## CONCLUSIONS

There has been a tendency to oversimplify the mechanisms by which climate change affects disease transmission and animal health status. Indeed, only a limited number of studies present validation of the direct effects of climate change itself. Climate change is to be considered in conjunction with the set of global factors today altering the earth terrestrial surface area and associated global biophysical systems.

The flare-up of novel pests and diseases of wildlife and livestock origin, and also the surge of food safety hazards, is likely to continue for decades to come. Risk analysis highlighting the implications of climate change in its broader context relies on the full consideration of the transmission ecology of pests and diseases. Transmission involving prominent free-living parasite stages is arguably more likely to be modulated by environmental factors including temperature, humidity and seasonality.

Risk management of emerging disease complexes in which climate change plays a role is best addressed under a “One Health” umbrella. For FAO, these efforts are centred around the collective biological risks in food production and supply chains.

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# Climate risk assessment and management in agriculture

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## INTRODUCTION

Climate risk in agriculture represents the probability of a defined hydro-meteorological hazard affecting the livelihood of farmers, livestock herders, fishers and forest dwellers. Risk refers to a probability that can be estimated from prior information, while uncertainty applies to situations in which probability cannot be estimated. Both risks and uncertainties contribute to choice of appropriate management practices by the decision-makers in agriculture. Farmers to some extent understand the risks and uncertainties of climate at their location and optimize the management practices based on years of experience. However, growing demand, changing climatic conditions, intensification and spread of agriculture to marginal production environments warrants improved climate risk management and decision support systems to enable appropriate choice of practices and strategies to match the current and future climate risks.

According to the International Research Institute for Climate and Society (IRI)[1] , climate risk management (CRM) refers to the use of climate information in a multidisciplinary scientific context to cope with climate's impacts on development and resource management problems. Further, IRI's definition elaborates that climate risk management covers a broad range of potential actions, including early- response systems, strategic diversification, dynamic resource-allocation rules, financial instruments, infrastructure design and capacity building. CRM is the use of climate information to cope with possible impacts of climate change on development and resource management (African Development Forum, 2010).

According to the World Meteorological Organization (WMO)[2], climate-related risk management refers to appropriate climate information distribution through an efficient delivery system that can alert food officials to assure food and water security long before the actual natural hazard sets in. WMO has initiated development of a concept of CRM and is developing examples of best practices already in use in different parts of the world, especially in water and agriculture sectors. According to the United Nations Framework Convention on Climate Change (2011) CRM refers to different aspects of the risk management process, including: (a) risk assessments for informed decision-making; (b) risk reduction: planning and preparation; and (c) risk sharing, pooling and transfer in the context of adaptation. The World Bank (2006) defines CRM as assessment of threats and

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[1] http://portal.iri.columbia.edu/portal/server.pt
[2] http://www.wmo.int/pages/themes/climate/risk_management_overview.php

opportunities arising from existing and future climate variability, including those deriving from climate change and, where necessary, incorporated into the design of projects and plans.

It is widely recognized that CRM revolves around the use of climate information and focuses on better management of climate variability as a starting point to determine vulnerability to the current climate conditions, including variability and weather extremes and then to assess how vulnerabilities might change as a result of climate change. In this way, CRM highlights the current pressing issues while factoring in projected future changes. In the agriculture sector, the approach is considered as valid as many developing countries are only partly adapted to current climate conditions. The CRM approach is of immediate relevance and benefit to smallholder farmers. The approach focuses on a coordinated response for addressing climate risks with committed engagement of farmers, herders, fishers, agricultural support services, institutions and enabling policy to build sustainable livelihoods resilient to climate risks (Figure 1).

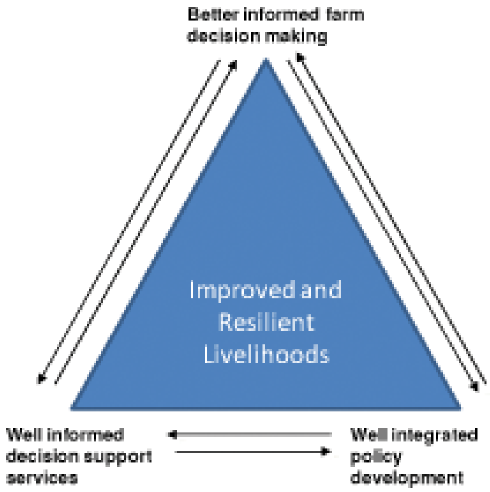

**Figure 1. Coordinated response for assessment and management of climate risks in agriculture**

In this paper, CRM is defined as a systematic process of identifying, analysing and responding to hydro-meteorological  risks at varying temporal and spatial scales. The approach brings together the synergies of adaptation to climate change and disaster risk reduction (climate-related) by focusing on actions that can be taken now to improve adaptive capacity and preparedness to cope with the current climate variability and to build resilience to better respond to the impacts of climate change. This covers a broad range of potential actions including early warning systems, weather and climate information application for risk and opportunity management, optimization of farm management practices for sustainable production, communication to the end-users of climate information and institutional-level decision-support systems such as medium-term warning systems, early warning systems and humanitarian response, crop monitoring and yield forecasting, agricultural insurance,, and development and application of data, tools and methods. Capacity building, gender considerations, cooperation and collaboration, and mainstreaming into plans, programmes and policies are integral to the overall CRM approach.

## CLIMATE RISKS IN AGRICULTURE

Agriculture is deeply interconnected with weather and climate, the main drivers of agricultural production, but also the dominant factors in the overall variability of food production (Selvaraju, Gommes and Bernardi, 2011) and a continuing source of disruption to ecosystem services (Howden *et al.*, 2007). Rainfall quantity and its distribution are key factors determining the rainy season characteristics, farming systems, field crop production and livestock rearing. Both interannual and intraseasonal rainfall variability constrains crop production in the tropics and subtropics.

In semi-arid tropics, unreliable rainfall combined with high evaporative demand and soils with low water-holding capacity and high run-off potential result in a high risk of water deficit at any stage of crop growth (Muchow and Bellamy, 1991). Frequent soil water deficit during early plant development, resulting in seedling mortality, retarded development and reduced yield, are very common. There are many instances where water deficit during the later stages of crop development is apparent. The wet spells and excessive rainfall events during the rainy season create waterlogging in the root zone, reduce plant growth and hinder field operations.

The rainy season duration is one of the primary factors affecting crop production prospects. Within a specific location, rainy season onset and final rain date are varying greatly from one cropping season to another. The variation of onset explains the significant variation in season duration since the onset date is more variable than the end date of the rains. Early onset of rains, relative to the mean date of onset for a given location, results in a longer growing season (Sivakumar, 1988). However, the relationship between onset date and seasonal rainfall duration is not always linear as rainy season characteristics are uncertain.

In addition to seasonal rainfall variability, higher growing season temperatures can have dramatic impacts on agricultural productivity, farm incomes and food security (Battisti and Naylor, 2009). Temperature during the cropping season often exceeds the optimum for physiological processes such as phenology, leaf area development, assimilate accumulation and grain filling. High air temperature around flowering can reduce pollen viability and grain set in major cereals of the tropics (rice, maize, sorghum, etc.). The incidence of high soil temperature during crop establishment is also a threat in semi-arid and arid environments. Soil surface temperature greater than 60 °C is common in Africa, India and Australian semi-arid tropics, and seedling mortality or thermal injuries are frequent.

Intraseasonal variability leads to extreme climate events that have direct impact on crop production and livelihood opportunities in the agriculture sector. For example, an unprecedented deficit of 49 percent in the all-India average rainfall in July 2002 led to a major drought, while rainfall was close to normal during all the other months of the rainy season. This led to a decline in farm-level crop productivity especially due to mid-season breaks in the monsoon activity. Farmers and herders often lose all the investment made during the season until the occurrence of climate extremes. Extreme climate events during the cropping season are posing a major threat to the agriculture sector. FAO’s global information and early warning system on food and agriculture indicates that sudden-onset disasters – especially floods – have increased from 14 percent of all natural disasters in the 1980s to 20 percent in the 1990s and 27 percent since 2000 (FAO, 2008).

Risk of climate variability affects dairy, meat and wool production, mainly arising from its impact on grassland and rangeland productivity. Heat distress suffered by animals reduces the rate of animal feed intake and results in poor growth performance (Rowlinson, 2008). Multiple climate-related risks cause far-reaching consequences for the livestock sector. For example, “dzud” in Mongolia – a multiple natural disaster consisting of a summer drought resulting in inadequate pasture and production of hay, followed by very heavy winter snow, winds and lower-than-normal temperatures – prevent livestock from accessing pasture or from receiving adequate hay and fodder. During 1999–2001, Mongolian herders in particular experienced the worst "dzud" in the last 30 years, where they lost more than 25 percent of the total number of their livestock, which was ten times higher than the normal year (AIACC, 2006).

Climate variability and climate extremes are already having impacts on agricultural production systems. Future changes associated with climate change will present additional challenges (Karl *et al*., 2008). The intensity of tropical cyclones (Knutson *et al.,* 2010) and frequency of heavy precipitation events are very likely to increase over many areas during the twenty-first century. At the same time, the proportions of arid land are projected to increase, in addition to a tendency for drying during summer, especially in the subtropics, low and mid latitudes (Bates *et al*., 2008). According to IPCC (2012), it is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the twenty-first century over many areas of the globe; and there is medium confidence that droughts will intensify in the twenty-first century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration.

Climate change threatens agriculture biodiversity; IPCC (2007) projected that approximately 20–30 percent of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5–2.5 °C over 1980–1999 levels. The range of crop weeds, insects and diseases is projected to expand to higher latitudes (Rosenzweig *et al*., 2001). Coastal zones and fisheries are particularly prone to risks associated with rising sea levels, changes in ocean salinity, cyclones, and a decrease in fish stocks and availability due to increasing water temperature (Hall-Spencer, Rodolfo-Metalpa and Martin, 2008).

Lobell *et al*. (2008) conducted an analysis of climate risks for crops in 12 food-insecure regions to identify adaptation priorities, based on statistical crop models and climate projections for 2030 from 20 general circulation models. Results indicated South Asia and Southern Africa as two regions that, without sufficient adaptation measures, will likely suffer negative impacts on several crops that are important to large food-insecure human populations. Battisti and Naylor (2009) used observational data and output from 23 global climate models to show a high probability (>90 percent) that growing season temperatures in the tropics and subtropics by the end of the twenty-first century will exceed the most extreme seasonal temperatures recorded from 1900 to 2006. In temperate regions, the hottest seasons on record will represent the future norm in many locations.

## MANAGING CLIMATE RISKS TO ADVANCE ADAPTATION TO CLIMATE CHANGE

Climate risk management (CRM) in the context of climate variability is integral to a long-term strategy for adapting agriculture to climate change. Effective climate change adaptation requires spatially and temporally downscaled climate change projections. Climate change projections are the key to impact assessment and direct adaptation planning, but are often seen to be a major constraint in transforming them into locally relevant adaptation actions owing to broader spatial scale and uncertainties. Nonetheless, countless studies have highlighted the issues of uncertainty and stressed that these uncertainties are not an excuse for inaction. Climate uncertainties present an additional challenge, but should not be a stumbling block for designing adaptation actions focusing on baseline issues and more towards longer-term resilient adaptation.

Adaptation to climate variability and extreme events serves as a basis for reducing vulnerability to longer-term climate change. Development of long-term adaptation strategy in agriculture depends on addressing similar issues in the short-term, recognizing the fundamental understanding that adaptation is a location-specific and continuous learning process (FAO, 2008). In addition, the action also contributes to current development priorities, reduces vulnerability (win–win opportunity) and matches with the shorter planning horizons of the farmers. CRM identifies immediate actions that are needed to manage the climate variability that is currently affecting farmers and herders. Furthermore, the impacts of possible interventions also become evident and verifiable in the short term, making them more attractive to policy- and decision-makers.

The African Development Forum (2010) proposes that better understanding of climate variability and improved management of its associated risks present a real promise to decision-makers seeking to understand how to adapt to climate change. It is understood that the patterns or trends of the past climate can tell us something about what future climate could be. Strategies developed to manage year-to-year climate variability go a long way towards building resilience and managing the risks of climate change.

## COMPONENTS OF CLIMATE RISK ASSESSMENT AND MANAGEMENT

Integration of climate information in risk management and adaptation planning is one of the priorities for sustainable agriculture. The approach of climate risk assessment and management has been adapted mainly in the following domains considering recent developments in weather monitoring, climate data analysis, crop–weather relationships, seasonal forecasting and economic modelling:

- inclusion of modern methods/tools for climate data sourcing and analysis, automatic meteorological measurements (rainfall, temperature, wind, etc.) at the local level and/or satellite rainfall estimation products available on a near real-time basis and seasonal forecasts;
- analysis of climate risks and assessment of climate impacts using crop–weather interactions;
- integration of economic models, linear and non-linear optimization methods and risk perception by farmers;
- preparation of advice to farmers and access to modern information and communication technologies.

All these components contribute to provide knowledge on the full range of crops to be planted, inputs that might be used and practices to be followed, so that farmers and herders will be prepared to execute management decisions at short notice. The operational components of climate risk assessment and management include: (i) collect real-time local, weather and crop information; (ii) analyse climate risks, vulnerabilities and impacts and management options based on local conditions (e.g. soil, farming practices); (iii) develop management alternatives based on the socio-economic context of the decision-makers; (iv) communicate the management options to the decision-makers in the form of advisories. The advisory should be based on type of enterprise, historical climate risks, current season weather conditions and seasonal climate forecasts.

### Establishing data and information for analysis

Data and information requirements include climate data, cropping systems, knowledge on local environmental conditions and agricultural practices, costs of inputs, market price, etc.

- Climatic data: historical rainfall, evaporation records, average and maximum/minimum temperatures and other selected climatic records and climate change scenarios.
- Knowledge of local conditions: land slopes, surface drainage, soil depth and water-holding capacities, fertility status, specific soil problems (salinity, hardpan, etc.), agroclimatic risks.
- Farming and cropping systems: crop, livestock, production systems including crop species, their specific cycle, plant population, water requirements, etc.
- Socio-economic data: socio-economic conditions (access to inputs, credit, etc.), household strategies, objectives, risk perception and technical support (institutions).

The climate risk assessment emphasizes the comparison of current quantitative data with historical information on trends and impacts. Daily rainfall records are essential in order to determine rainfall onset date and relate rainfall probabilities to crop growth stages. The key activities of the component are: analysis of decision problems; information need at the farm level; review of existing climate data availability and quality; information synthesis related to cropping pattern, soil types, natural resources and management practices; assessment of the suitability of sources of real-time weather and climate-forecast products and modern data sourcing (e.g. remote sensing).

### Climate analysis and crop weather interactions

Field application of CRM involves a series of iterative analyses of the historical rainfall records, specifically oriented to crop production requirements. Subsequently, the analytical and interpretative process should consider seasonal climate forecasts and appropriate decision alternatives for response. Historical data enable risk assessment for present or planned cropping systems and quantification of risks related to actual dates when rainfall first meets crop season onset requirements. Analysing climate indices and climate/crop interactions includes assessment of historical risk patterns for crops and cropping systems, rainy season characteristics, onset, end and length of growing period, intraseasonal rainfall variations including wet and dry spells, risks for crops/varieties related to rainfall amount and duration.

Rainfall onset is the date of onset of the growing season as the key variable to which all other seasonal rainfall variables are related. However, defining onset criteria is considered important in this analysis and depends on type of crop and soil factors. Onset relations are crucial because they indicate how the seasonal rainfall is expected to behave. Rainfall probabilities should be worked out related to time periods of specific crop growing stages.

A farmer's signal for sowing may be either a fixed calendar period (window), or attainment of some arbitrarily selected buildup of stored soil water or attainment of a fixed rainfall threshold. Total seasonal soil moisture is the amount of water stored in the crop root zone at the time of germination, plus the amount that falls during the season from germination to crop maturity. Seasonal rainfall prediction provides the probabilities of exceeding a specific quantity of rainfall that poses potential risks to crop yields.

Climate risk assessment should be followed by formulation of management decisions that avoid risk to the greatest extent possible. Risk assessment is integrated into the analytical process through functional relations and crop models, which estimate potential levels of crop performance associated with different predicted levels of rainfall. Simple book-keeping procedures of water balance, water balance models and dynamic crop growth models are widely used for risk assessment. Community-based bottom-up approaches contribute to develop information on local perception of risks.

### Optimization of farm management practices conditioned by climate

Crop-season-based rainfall probabilities can be made more informative with specific details on adaptive management strategies. The management strategies should be optimized for early and late onset of rainfall, good, average and bad seasons. Therefore, the optimization approach builds on the primary objective of adjusting farm management strategies based on current and future weather conditions. Modern computer technology and, in particular, decision support systems can facilitate the comparison of management strategies by simulating the crop yield and gross margins.

The optimization tools are flexible, facilitate the alteration of the management practices and assess the possible consequences. Economic optimization techniques are the tools to find out the optimal management practices to reduce the impact of possible rainfall shifts from one season to another. The key activities of this component are: linking past performance of risk factors to crop performances; optimizing management practices (planting methods, cultivar selection: matching maturity to expected rain duration, crop selection: matching average daily water requirements to average seasonal rainfall patterns, optimization of plant populations, fertilizer application, weeding, intercultural operations and harvesting based on seasonal rainfall behaviour and land allocation under various crops depending on constraints, etc.) considering the farmers' objectives and adjusting cropping practices to fit selected crops and targeted rainfall.

### Preparation of farmer advice and communication

Farmer advice should be based on historical weather data and risk assessment related to current weather conditions, climate forecasts and optimal management practices. The major factors to be considered for preparing advice to farmers are: (i) rainfall probability analysis; and (ii) design of optimal cropping systems and management practices related to seasonal climate forecasts. Analysis of historical rainfall, data from real-time observation and modern climate monitoring and seasonal climate impact outlooks provide guidelines for selection of suitable management options based on rainfall behaviour. Full details should be communicated to farmers, who prepare in advance to follow their preferred choice.

Farmer advice needs to be simple and targeted on key management factors, such as adapted species or matching cultivar maturity, meeting the requirements of expected duration of the rainy season. These types of targeted agro-advisories need to be prepared by Agromet or extension services and other intermediary organizations dealing with CRM. It is important to note that the advisories are not just recommendations, but are the options that may be considered by the farmers to reduce the risks of climate variability. The main activities of this component involve: preparation of advisories incorporating rainfall probabilities, optimal management strategies, identification of appropriate communication channel to deliver the information and conduct of climate workshops to enhance the decision capacity of decision-makers. The approach should facilitate interaction between providers and users of information.

## CLIMATE RISK MANAGEMENT AT FARM LEVEL

### The farm as a system

The farm management decisions have a significant role in deciding the productivity of the farm. The production and management systems within the farm and the economics of overall farm management and its performance depend on both on-farm and off-farm factors (Figure 2). The climatic conditions are major external factors affecting crop growth and yield at the field level. The internal factors generally relate to decisions on allocation of resources, selection of enterprises, application of inputs and management.

The CRM procedures at farm level should consider both external and internal factors of production, agronomic management practices and climate data (observed or forecast). As each type of risk poses a different type of threat to crop production, these risks must be addressed by location-specific management practices. An illustrative example of the major sources of risk, nature of threat and field level decisions and actions is provided in Table 1.

### Risk management practices at farm level

At farm level, appropriate choice of management practices is the part of risk management that refers to achieving the farm household's goals as efficiently as possible in the

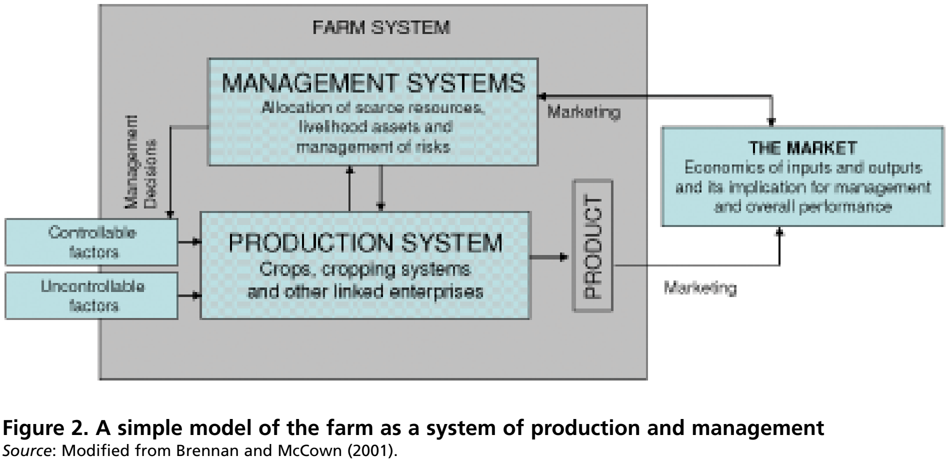

**Figure 2. A simple model of the farm as a system of production and management**
*Source*: Modified from Brennan and McCown (2001).

**Table 1: Sources and nature of risks associated with seasonal rainfall behaviour and appropriate field level responses**

| Source of risk | Nature of threat | Field level decisions and actions |
|---|---|---|
| Wet spells | Waterlogging of crop root zone | Land configuration; drainage of excess water. |
| Dry spells | Crop water deficits | Plant population adjustment, skipping nitrogenous fertilizer application, provision of supplementary irrigation. |
| Early season dry spell following onset | Seedling death; low plant density | Increase onset soil water criterion and/or delay earliest planting date |
| Middle season drought | Crop yield loss if drought occurs at critical growth stage | Adjust ranges of planting dates to fit phenology of crops; select suitable crop types |
| Terminal drought and early cessation of rains | Rainy period duration inadequate for crop maturity | Select maturity classes of crops/cultivars based on rainfall analysis and expected rainfall behaviour |
| Deficit in seasonal rainfall amount | Crop water deficit with resultant yield loss | Select crop types with appropriate average daily water requirements; land preparation and tillage for *in-situ* moisture conservation. |
| High year-to-year rainfall variability | Degradation of grazing lands and poor financial performance of livestock enterprise | Adoption of safe stocking rate (livestock) |

**Table 2: Farmers' seasonal actions and their influence on the factors of crop and livestock production**

| Farmers' actions on optimal management practices | Influence on factors of crop production |
|---|---|
| Land and seedbed preparation | Imparting slopes to plant rows and modifying infiltration characteristics of the soil, thus increasing water retention and reducing run-off. |
| Selection of crops to be planted | Determining water requirements, potential for soil water extraction during dry periods. |
| Selection of cultivars | Determining length of the growing season from germination to physiological maturity |
| Selection of seed rates and spacing between rows | Influencing crop water requirements and pattern of soil water extraction |
| Selection of initial fertilizer types and rates of application | Determining potential water use efficiency and reducing the risks of extreme rainfall. |
| Plant population adjustments and fertilizer application after crop establishment | Conforming crop water requirements and/or potential water use efficiency based on observed early season rainfall. |
| Adjusting animal stocking rate | Improved carrying capacity and arresting degradation of grazing lands |

face of physical, environmental, socio-cultural and other constraints. Risk management helps to optimize the farm decisions to obtain maximum possible net benefit over time. Sustainability, environment friendliness and resilience should also be explicitly considered while setting objectives for selecting optimal management practices.

As a new season approaches, a number of actions should be taken by the farmers/herders, which shape the performance of the enterprise during the entire season. These actions are related to land, seedbed preparation, selection of crops and varieties, selection of seed rates and spacing, initial fertilizer application and livestock stocking rate (Hammer, Nicholls and Mitchell, 2000). An illustrative example of farmers' actions and their influence on factors of crop production is given in Table 2.

Farmers' actions on optimal management practices can influence the factors of production favourably and reduce the climate risks and uncertainties. This reiterates the importance of the need to assist farmers in supplying information that matches with existing

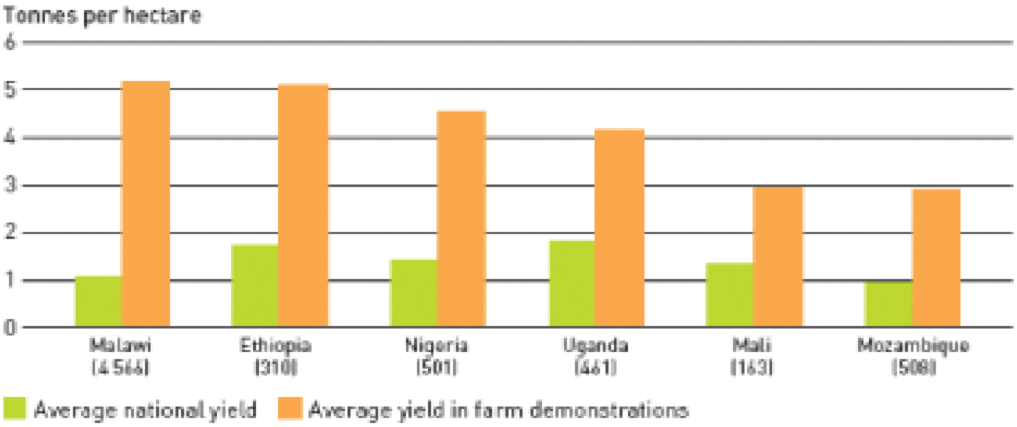

**Figure 3. Exploitable yield gap for maize**

Notes: Number of plots in parentheses. Open pollinated improved varieties in all cases except Nigeria, which uses hybrids. Data for 2001 for Ethiopia, Mozambique, Nigeria and Uganda; 2002 for Malawi; an average of 2001, 2002 and 2004 for Mali.
*Source*: World Bank (2007).

climate risks. Farmers should be able to plan/adapt their practices, given the historical and recent past climate and weather conditions, and near-term likely climate to enable proactive management of climate risks.

The risk assessment based on seasonal and intraseasonal climate information is of a great value to promote advance planning. More efficient and relevant seasonal advisory services enable farmers to reduce the risks and stabilize their yields through optimal management of resources and inputs. The optimal management practices enhance the effectiveness of farm performance. Improving risk management approaches with concepts of farm level optimization techniques would be more suitable to manage risks of climate variability and change at farm level.

## Managing full range of climate variability and bridging farm-level yield gaps

In general, decision-makers at farm level are vulnerable to climate variability for two reasons: (i) inherent variability and uncertainty associated with climate; and (ii) missed opportunities owing to risk averse conservative strategies followed by the decision-makers. Hansen *et al.* (2007) reiterated that uncertainty associated with climate variability, combined with risk aversion on the part of decision-makers, causes substantial loss of opportunity in climatically favourable and even average years. This implies that low input application during good or better than normal seasons will miss the opportunities to exploit the favourable conditions. Efforts to reduce yield gaps should consider managing full range of climate variability (good, bad and average seasons) on either side of the distribution instead of targeting only the extremes (drought, floods, etc.).

Farm yield gaps in developing countries tend to be very large (Figure 3). Improving agronomic management and input use efficiency are the most important means to reduce the yield gaps. Climate information that reduces the uncertainty that farmers face during a given season has potential to improve the effectiveness of production technologies and input use efficiency. Reducing uncertainty enables the farmers to adopt improved

**Table 3; Agricultural decisions at a range of temporal and spatial scales that benefit from climate information**

| Farming decisions | Frequency (years) |
|---|---|
| Logistics (e.g. scheduling of planting/harvest) | Intraseasonal (>0.2) |
| Tactical crop management (e.g. fertilizer/pesticide use) | Intraseasonal (0.2–0.5) |
| Crop type (e.g. wheat or chickpea) | Seasonal (0.5–1.0) |
| Crop sequence (e.g. long or short fallows) or stocking rates | Interannual (0.5–2.0) |
| Crop rotations (e.g. winter or summer crops) | Annual/biannual (1–2) |
| Crop industry (e.g. grain or cotton; native or improved pastures) | Decadal (~10) |
| Agricultural industry (e.g. crops or pastures) | Interdecadal (10–20) |
| Land use (e.g. agriculture or natural systems) | Multodecadal (20+) |
| Land use and adaptation of current systems | Climate change |

technology, intensify production during better years and reduces the risks during the bad years. Climate information services enable farmers to adopt new technology and thus sustainable intensification of production by understanding spatial and temporal climate variability.

## CLIMATE INFORMATION FOR RISK MANAGEMENT AND SUSTAINABLE PRODUCTION

Advances in climate prediction, analysis and synthesis of climate knowledge have helped improve CRM with the potential to enhance livelihood opportunities in agriculture (Selvaraju, Gommes and Bernardi, 2011). Climate information at all time scales is crucial to advance risk management and improve sustainable production. The climate information and likely decisions are: (i) climate change scenario to understand the trend and alter system-level decisions (cropping or grazing); (ii) seasonal climate information to make strategic decisions (crop type, marketing, forward selling, livestock herding rate, etc.); (iii) intraseasonal forecasts to schedule tactical operations (e.g. fertilizer, water and other adjustable inputs); and (iv) weather forecasts for the day-to-day operations. Climate information at a range of temporal scales that benefit agricultural decisions (Meinke and Stone 2005) is presented in Table 3.

### Weather forecasts and early warning systems

Short- to medium-range weather forecasts and early warning systems can be useful elements of the decision-making process in CRM (Challinor, 2009). Intraseasonal to interannual climate variability impacts the agriculture sector and, therefore, many agricultural decisions can benefit from high-quality, reliable predictions. Donald *et al.* (2004) emphasized that intraseasonal forecasts are considered essential for making appropriate decisions to modify strategies that reduce vulnerability for smallholder farmers.

There are several indices and methods used to explain the intraseasonal climate variability relevant to agricultural applications. The passage of the Madden-Julian Oscillation has been described to explain patterns of suppression and/or enhancement of rainfall to be forecast beyond the synoptic scale (Bond and Vecchi, 2003). Propagation characteristics of the Monsoon Intra-Seasonal Oscillation provide indication of active and break monsoons in southern Asia (Hoyos and Webster, 2007). Tactical risk management can be improved through the application of intraseasonal forecasting capabilities that will allow farmers to assess the timing and likelihood of rainfall events and temperature fluctuations at time scales of up to six weeks.

### Seasonal climate forecasts

Advanced information in the form of seasonal climate forecasts has the potential to improve farmers' decision-making, leading to reduced risks and increased opportunities. Climate information (seasonal) has the potential to improve livelihoods, enable farmers to adopt improved technology, intensify production and enhance soil fertility, and farmers are capable of investing in more profitable enterprises when conditions are favorable (Hansen *et al.*, 2007). The approaches to seasonal to interannual climate predictions and sources of predictability, including ENSO (El-Nino Southern Oscillation)-related indices, offer a greater potential for risk reduction and opportunity management. These developments have the capability to improve the economic return for both smallholder farmers and rural companies, such as grain traders, sugar mills and cotton gins (Meinke *et al.,* 2006).

### Addressing gaps in climate information services

Although significant developments have occurred in prediction and dissemination of weather and climate forecasts in recent decades, this information has not yet been utilized adequately and not integrated effectively into agricultural development. This is largely due to the gap between information provision (supply) and users' (demand) of the information. The demand for climate information is diverse – localized, timely and easily understandable information products are needed to translate information into actions. On the one hand, diverse cropping systems and decision cycles associated with crop and livestock activities in smallholder farming systems pose difficulties in customizing information products to match the local activities. On the other hand, inadequate access, mismatch between farmers' needs and the scale, content, format or accuracy of current operational forecasts limit the climate information use (Phillips, 2003; Ziervogel, 2004). The supply of climate information is often constrained by insufficient data and resolution. The information is often general, and technical terms are not easy to understand on several occasions and very narrow, specific information could not influence the local decisions.

To address the above gaps, the information products should be tailored to suit the user needs. The meteorological agencies, agriculture service providers, irrigation managers, input suppliers, market intermediaries, local cooperatives, microfinancing, farmers, fisherman and livestock herders need to collaborate and establish the most convenient and appropriate user interface platforms (UIPs) to share the information products and receive feedback. Strengthening/upgrading local observation networks, capacity building to understand the user needs and also to generate user relevant information products, interpretation and development of customized information products and communication of information along with associated uncertainties to end-users are essential to improve climate information services to farmers.

## BETTER INFORMED INSTITUTIONAL DECISION SUPPORT SERVICES FOR CLIMATE RISK MANAGEMENT

The agricultural support services and institutions at the national and local levels need risk information for planning their activities and providing timely services to the ultimate beneficiaries. Better informed decision-support systems can be very efficient and capable of providing need-based information services to the farmers, livestock herders and fishers. Users of climate information at institutional level need historical climate information, climate monitoring products and forecasting in different time scales for institutional decisions. In most cases, effective use requires that raw climate information be translated into quantitative information (soil water status, pest and disease risk, vegetation conditions, crop yields etc.), with sufficient explanation of uncertainties.

The agriculture support institutions (extension and research) should offer and also make use of information about agriculturally relevant precipitation indices (deviation from normal, water stress, agriculture season length (beginning and end) etc.), progress of the precipitation indices from the past to current, near real-time information about the crop state and early-warning systems for humanitarian response.

### Early warning systems and humanitarian response

Emergencies are on the rise – especially sudden onset disasters and series of low and high rainfall extreme events. The number of floods has increased from 14 percent of all natural disasters in the 1980s to 20 percent in the 1990s and 27 percent since 2000. Worldwide, flood occurrences have risen from about 50 floods per year in the mid-1980s to more than 200 today. Droughts followed by floods are not uncommon (e.g. Niger in 2009 and 2010). Need-based early warning systems have important implications for humanitarian response activities. Early warning systems help timely mobilization of resources needed to prepare for, and respond to, emergencies in order to save lives and protect livelihood systems. Routine climate monitoring and weather forecasting should provide necessary inputs for food security early warning and to develop scenarios for food security outlooks. Drought monitoring systems are also being used to focus emergency response and also pro-active management of impacts. Drought early warning systems can help achieve a greater level of drought preparedness and drought mitigation. These systems can be improved by integration of spatial databases, including remotely sensed data, with agronomic models.

### Crop monitoring and yield forecasting

Analysis of meteorological and climatic data allows providing near real-time information about the crop state, with the possibility of early warning. Crop monitoring and yield forecasting allow timely interventions by the government to avoid crisis. The strategies include contingency plans, alternate livelihood options and response plans for food aid. Large-scale monitoring of agriculture and crop-yield forecasting generally rely on: (i) regionalized analyses of cultivated areas, crop type distribution and crop condition based on near-real-time satellite imagery merged with available *in-situ* observations; (ii) meteorological monitoring and mid-term forecasts based on observation networks and model outputs; and (iii) regionalized knowledge of agricultural systems and their sensitiv-

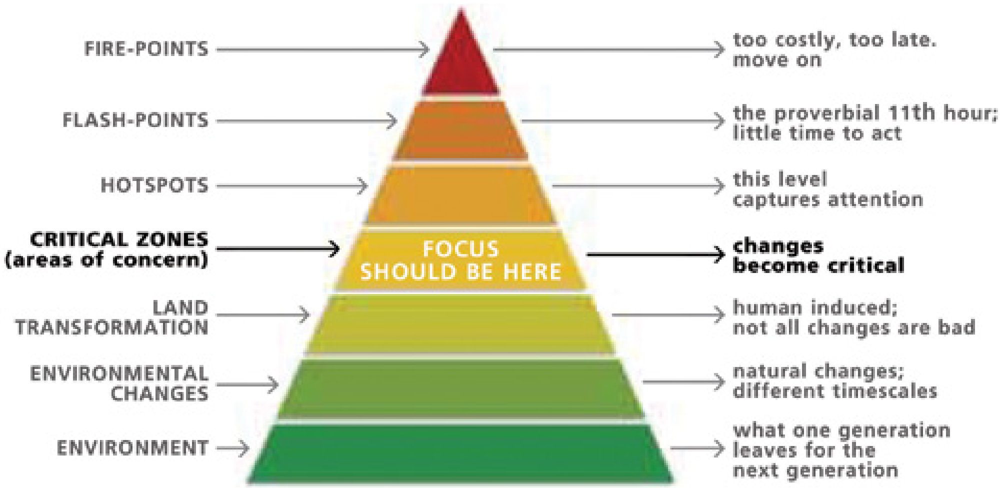

**Figure 4. Hotspots pyramid showing an idealized progression of environmental change**
*Source*: FAO (2009).

ity to meteorological conditions. The crop monitoring and yield forecasting capabilities in developing countries are weak and need strengthening at the national level with more emphasis on collection of data such as meteorological, agro-meteorological, soil, remote sensing and agricultural statistics.

## Medium-term warning systems (5–10 years)

Policy-makers need advance information on likely hotspots of vulnerabilities and sensitivities. Thus a medium-term warning system (5–10 years) can fill the gap between seasonal-scale assessments and long-term impact projections. Identification of the future areas of concern and likely hotspots of vulnerabilities and sensitivities are critical to reduce the risks in a time frame of 5–10 years. The pyramid (Figure 4) shows a simplified progression of environmental changes (forests, irrigated lands, rainfed cultivated areas, fisheries, etc.) that can result from environmental interactions with human activities (FAO, 2009).

Hotspots are locations of degradation of either the managed or the unmanaged environment. They indicate situations when mitigative action remains possible at relatively higher costs and appear before conditions deteriorate further to the flashpoint stage. The flashpoint stage offers a brief, last window of opportunity for policy-makers to react before environmental collapse becomes inevitable; when (if) they do choose to react, however, the necessary measures for recovery will prove extremely costly in terms of time, money and political capital. Fire points indicate that environmental conditions have collapsed – it is too late for policy-making, as the degradation has overwhelmed all chances for recovery, and exhausted fields, for example, have to be abandoned for generations to come.

Policy-makers should focus not on hotspots but on critical zones (areas of concern) because at this stage of the continuum not only does enough scientific evidence of degradation exist but so does enough lead time to pro-actively implement relatively low-cost yet highly effective measures to arrest or reverse the devastation and avoid the negative consequences that accompany passage into the hotspots stage.

## Agricultural insurance

FAO (2005) estimated that the total annual agricultural and forestry insurance premiums worldwide in 2001 amounted to some USD6.5 billion, representing just 0.4 percent of the estimated total farm-gate value of agricultural production globally. As the current insurance mechanisms do not adequately cover the millions of smallholder farmers, institutional support systems should play a major role in providing localized and needs-based climate information to farmers so as to encourage them to make use of insurance mechanisms.

Index-based insurance products for agriculture represent an attractive alternative for managing weather and climate risk (Skees, 2008). Agricultural insurance is growing as a result of increased commercialism and availability of new types of insurance products. For the government, insurance mechanisms provide some predictability to weather risk financing and offer enough lead time for emergency responses to manage livelihood crisis. This lessens the weather/climate effects by securing needed resources sooner to protect livelihoods.

Provision of localized and needs-based climate information to promote index-based weather insurance requires strengthening of weather observation networks, monitoring of extreme climate events, standardization of indices, data sharing, early warning systems and capacity building. The index-based weather insurance systems require the support of national meteorological and hydrological services to ensure high-quality weather data, monitoring instruments and procedures to downscale weather information to produce real-time crop yield indices covering a specific agro-ecological region.

## Data, tools and methods

Historical climate data are the key to assist CRM efforts. But the major problem is that both synoptic and agrometeorological stations in developing countries are thin and declining in the recent decades. For example, there are just over 1 150 World Weather Watch stations in Africa giving a density of 1/26 000 km$^2$. Even the data collected from several existing stations are not readily available for analysis and data remain on paper and are inaccessible to users. Efforts are needed to fill the gaps and increase the resolution of spatial interpolation to fill the missing data. Proxy measurements using satellites and rainfall estimation can partially contribute to the analysis in areas where very sparse data are available.

Risk identification is often carried out through quantitative and qualitative tools and methods. Traditionally quantitative top-down approaches are used for risk identification and analysis. The community-based qualitative approaches can bring local context and traditional wisdom into the analysis. Community-based approaches provide strong, locally-relevant data and information about livelihood profiles and local vulnerability towards development of risk maps. Livelihood analysis interprets climate-related hazards and builds on local livelihood strategies. Institutional support for livelihood analysis can guide preparation of risk and vulnerability maps by dividing a region into areas with relatively homogeneous patterns of natural resources. The products can provide advance information about the livelihood baseline and vulnerability to weather and climate phenomena.

## STRENGTHENING TECHNICAL AND INSTITUTIONAL CAPACITIES

Strengthening the capacity for agrometeorological observation, the development of customized forecasting products, the management of data and modelling for climate impact assessment and application of climate information at the farm level, and strengthening of decision-support systems at the institutional level are the priority (Selvaraju *et al.*, 2011). Agricultural extension services need to be strengthened in order to address climate risks and plan for adaptation if these are to provide an efficient interface between policy-makers and the farming community.

Strengthening of community networks, local institutions and norms and relationships is critical for managing climate risks. Local networks shape the farmers' social interactions leading to better participatory decisions (Meinke *et al.*, 2006). Farmers' knowledge sharing mechanisms relevant to local context are the key for effective communication of value-added climate information (Selvaraju, Meinke and Hansen, 2004). Farmer participatory climate workshops, Farmer Field Schools (FFS), local climate information centres and innovative information and communication technologies (e.g. mobile networks, etc.) facilitate rapid dissemination of information products to the farmers and livestock herders.

National meteorological and hydrological services need to understand the information requirement of agriculture support services and farmers and accordingly mainstream development of weather and climate information products. Agricultural support services and community-based organizations should engage themselves in development of contingency plans incorporating new technologies, improving impact data collection, monitoring and analysis (including climate change), development of impact outlooks and management alternatives considering local needs, and facilitate communication of information to farmers/herders.

## CONCLUSIONS AND RECOMMENDATIONS

The agriculture sector is highly exposed to climate risks. The majority of risks associated with production are because of adverse climatic conditions and inherent climate variability; and climate change represents an additional threat. Climate risks are often translated into poor crop yields and suboptimal performance of livestock enterprises. The climate risk is capable of altering other risks such as asset depletion (damage and loss to assets as a result of extreme climate events), price risks (risk of falling or raising prices) and financial risk (from possible increase of interest, etc.).

Farm-level CRM should focus on optimization of management practices to reduce the impacts during bad years and enhance the opportunities during better than average and average years. Management of a full range of climate variabilities is an ideal option to effectively reduce the risks and bridge the farm-level yield gaps. Recent advances in climate prediction and climate information services offer a huge potential for optimizing management practices, bridging yield gaps and sustainable production. Climate information on various time scales: (i) climate change scenario; (ii) seasonal climate information; (iii) intraseasonal forecasts; and (iv) weather forecasts and early warning systems, present immense opportunities to manage the full range of climate variability.

The agricultural support services, institutions at the national and local levels need risk information for planning their activities and to provide timely services to ultimate beneficiaries (farmers, herders, etc.). There are number of decision support systems already developed and tested in many countries. For example, advances in crop forecasting, early warning systems, humanitarian response and agriculture insurance provide decision support to the institutions to deliver timely and needs-based interventions at various spatial and temporal scales. Agricultural support services, including agricultural research and extension, national meteorological and hydrological services, community-based local institutions (e.g. farmer cooperatives) and the private sector (e.g. input suppliers, seed companies, etc.) are well placed to contribute to CRM.

A number of areas need the urgent attention of both the meteorological and agriculture community to effectively address climate risks. The priorities include: a climate monitoring and data collection network in rural areas, systematic data archival and management to characterize natural resources and provide needs-based information to research, extension agencies and farmers, ensuring the use of modern information products, forecasts from regional and international centres at the national level, strengthening livelihood-based climate impact analysis to bring down the impact outlooks to the local context, deliver improved, reliable, timely, and locally understandable information products with management options for the end-users with a view to narrowing down yield gaps. The customized climate information products should consider inputs, credit, market and financial aspects.

The role of climate services in index-based insurance, crop monitoring and yield forecasting should be enhanced in both the public and private sectors to facilitate protection of livelihoods. Mainstreaming climate information services into food security early warning and humanitarian response, agriculture and food security policies, disaster risk management plans and programmes is crucial to sustain committed support from governments. Sustained communication channels need to be established to provide needs-based information and feedback to national meteorological and hydrological services, agronomic research and extension systems. Building a local farmers’ network and awareness-raising are key to enhancing trust at the community level. A number of cross-cutting elements, such as capacity building, awareness, gender and collaboration, are prerequisite in all aspects of CRM.

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# Coping with changes in cropping systems: plant pests and seeds

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## INTRODUCTION

The evidence for climate change is overwhelming, with the poorest countries and people most vulnerable who will suffer the most from its negative impacts. Maintaining food security is already critical for smallholder farms, and minimizing vulnerability in the face of change is becoming even more of a challenge. Increased variability due to different aspects of climate change results in greater exposure of marginal areas and small farmers to new risks.

Climate change causes highly variable environmental conditions, including:

- higher temperatures and shift of seasons;
- changes in rainfall and subsequent variation in water availability;
- extreme natural events, causing disasters;
- change in atmospheric gas composition.

Such changes generate variations in biological cycles – phenological phases of crops, timing of cropping seasons, agro-ecological zones and population dynamics of living organisms (including pests and invasive alien species) are all affected. The rate of climate change might possibly exceed the rate of adaptation of ecosystems, including cropping systems, creating many concerns on how to cope with such changes, particularly in relation to food production and availability.

Credible and scientifically robust studies on various cause–effect relationships of climate change are under current research, while the impacts of climate change are tangible, and negatively affect crop productivity and livelihoods of marginal rural communities. It is imperative to develop a sound understanding of these dynamics, and learn from previous experiences on coping with emerging changes and challenges.

The sustainable production intensification (SPI) is one of FAO's strategic objectives. SPI is promoted through the concept of *Save and Grow*[1] to increase production efficiency and to achieve sustainability in agricultural production, with a special focus on small farmers. The concept builds on local biodiversity and ecosystem functions to enhance productivity, and aims to increase efficiency in the use of agricultural inputs. Essential elements of *Save and Grow* are soil health and proper fertilizer management, conservation agriculture, management

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[1] http://www.fao.org/ag/save-and-grow/

of genetic resources and improved seed systems, integrated pest management (IPM), proper water management, enhanced pollination services and knowledge of local agro-ecosystems.

This paper focuses on IPM and seed systems as two key pillars of *Save and Grow*. We propose to learn from experiences on strengthening seed systems, and closely monitor the dynamics of plant pests and diseases to establish effective ecosystem approaches for management using environmentally acceptable science based tools.

## CHALLENGES

Agro-ecosystems are in a dynamic state. Many insects, diseases and weeds, generally defined as crop 'pests', are an integral component of agro-ecosystems. In naturally established agricultural systems, 'pest' species are in a shifting balance with other species (including those of their own natural enemies – parasites and predators) and crops, as components of local food webs. Their presence in any specific field varies in time, population level and relationship with other species as does their role (as pests or defenders). Such variations may depend on crop phenology, environmental conditions **and** agricultural management practices in the specific field (or area). Under certain circumstances, populations of such species may reach a level resulting in significant damage to crops, and thus become 'pests'. This change of status is often related to local management practices, including cropping patterns, host genotypes, and use of chemical fertilizers and pesticides that may have adverse effects if improperly used. In order to assess and manage decisions for minimizing disruption to the local ecological balance properly, it is essential to have a good understanding of existing species in the field and their role in the local agro-ecosystem. Understanding the local agro-ecological balance is at the core of good farming practices that farmers have been mastering for millennia, to provide food successfully for their communities.

Agricultural intensification over the last 50 years has focused on the introduction of new inputs and practices in traditional agro-ecosystems, which has led to higher productivity, but at the same time to increased vulnerability in agricultural systems, reducing their resilience and production sustainability.

Recent outbreaks of brown planthopper (*Nilaparvata lugens*) in rice in Southeast Asia represent a typical case of disruption of ecological balance by misuse of pesticides. This is now a common scenario in agricultural intensification: if pest management decisions are not supported by appropriate knowledge and understanding of ecosystem balance and their variations, both at field and at policy level, the whole agricultural system is at risk.

Based on such experiences related to agricultural intensification, new causes of vulnerability in agro-ecosystems caused by climate change can be looked at, in particular, focusing on the natural life cycles of different kinds of pests.

**Arthropods**. Life cycles and population levels of insects and spiders are sensitive to changes in temperatures as they are poikilothermic (organisms whose internal temperatures vary, often matching the temperature of the immediate environment). For these cold-blooded organisms, temperature is the single most important environmental factor influencing behaviour, distribution, development, survival and reproduction. Effects of temperature increase on these species have been studied by Kiritani in Japan (2006), based on a 1 °C increase in mean annual temperature over the last 40 years. This increase has resulted in a shift in species distribution range, reduction of winter mortality, earlier occurrence in spring and increased number of annual generations.

The same study also indicated that with present trends in increasing temperature, tropical and subtropical insect species may advance continuously poleward (as far as their cold hardiness allows) because they lack diapause in their lifecycles. Temperate species will expand stepwise, as they need to reach the required temperature to allow them to develop one additional generation before reaching the diapause stage. In fact, diapause introduction is driven by photoperiodic cues (Tobin *et al.*, 2008).

Differences in patterns of response to temperature change among insect species do affect relationships within food webs (host, pest, natural enemy) owing to changing phenology and their synchronization. This may result in the emergence of new pests as species may be released from natural control factors (predation/parasitization). Conversely, the new balance may also work in favour of the buildup in populations of natural enemies such as *Trichogramma* and egg parasitoids (*Apanteles*, *Cyrtorhinus*). These may be able to increase the number of generations per year earlier than their host species as a result of their lower thermal constant. Both possibilities demand good understanding to support development of new management strategies – defining the essential role of stakeholders and decision-makers at different levels: policy-makers, researchers, extension workers and farmers.

Interestingly, Kiritani also suggested that greenhouse culture represents a model of a temperate agro-ecosystem after global warming: most greenhouse pests are invasive species from subtropical or tropical origins and thus lack diapause. In the last 30 years, new pests, such as *Trialeurodes vaporariorum*, as well as another ten species, have invaded greenhouse cultures in Japan, and have been combated with increases of insecticide application on tomato (X4), eggplant (X7) and cucumber (X8). Without the identification/introduction/survival of natural enemies of these pests, global warming may result in a prevalence of invasive pest species and consequent increase in insecticide use. Similarly, insect-borne diseases, mainly viruses (CuYV, TYLCV, TSWV, etc.) may become important with global warming.

Global warming is also related to increased concentrations of greenhouse gases, such as $CO_2$, that will affect crop pests indirectly through changes in plants and vegetation composition, quantity and quality. Studies have been conducted on the impact of increased $CO_2$ and $O_2$ concentration levels (free-air gas concentration enrichment – FACE) to the level estimated for predictions for the mid-twenty-first century, demonstrating higher insect pressure (of Japanese beetle, potato leafhopper, western corn rootworm, Mexican bean beetle) requiring additional insecticide usage (Hamilton *et al.*, 2005).

**Pathogens** are sensitive to temperature changes and atmospheric gas composition, as these changes affect host plant growth and canopy shape/density and cause a change in microclimatic conditions in favour of disease spread and virulence. Plant disease agents will respond to climate change, but such responses will be difficult to predict owing to the complex relationship between host and pathogen mediated by local environment and management

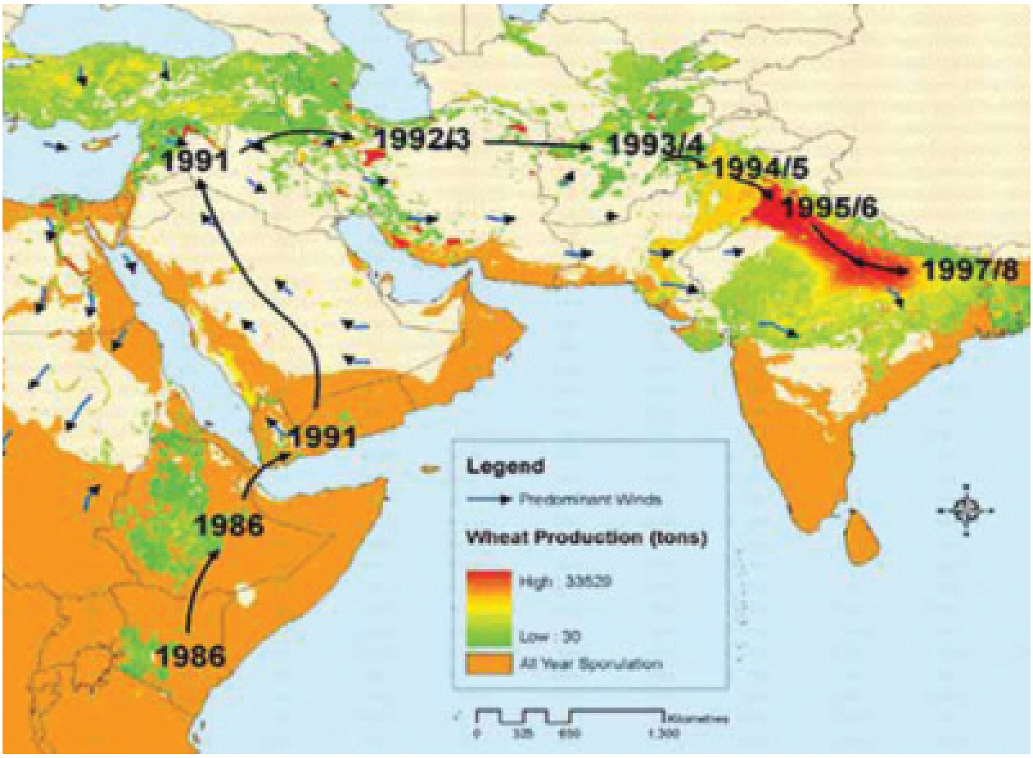

**Figure 1. Yellow rust pathway (1986–1993)**
*Source*: FAO (2008).

practices. In temperate climate zones, earlier onset of warm temperatures could result in an earlier threat from plant diseases (such as tomato late blight, *Phytophtora infestans*) with a potential for more severe epidemics and subsequent increase in fungicide applications.

A recently documented case is the spread of wheat rusts (Hodson, 2011), closely linked to conditions of temperature, rainfall distribution and relative humidity. Stem rust epidemics in the early twentieth century created a demand for studies on its spread and genetics, leading to the large breeding programmes at the core of the green revolution concept in the 1960/70s. Yellow rust emerged in the early 1990s with epidemics in North Africa, the Near East and Asia, and in the early 2000s stem rust resistance was broken by the Ug99 race lineage that emerged from East Africa and spread north and eastward. These and similar changes are linked with either continuous use of susceptible hosts or inappropriate management practices, but recently climate change is taking an increasingly important role. Studies conducted in India show increasing temperatures and relative humidity, and a decline of rainfall in Punjab. Such changes may lead to a higher incidence of pests and diseases and lower grain quality (Agarwal, Naresh Kumar and Pathak, 2009). Global initiatives were launched to mitigate the wheat rust threat, based on the need to have a sustained, collaborative, multidisciplinary effort, starting with careful monitoring and surveillance both at local and international levels. Adequate knowledge and understanding of pathogens in changing environmental conditions is required to respond effectively to these new threats.

Plant pathogen distribution and intensity will also be affected by moisture level and increased precipitation, as well as by $CO_2$ levels, affecting plant canopy structure and micro-environments, thus providing good shelter and higher reproduction rate for pathogen development. Finally, efficacy of fungicides may be affected by these variations causing an additional source of uncertainty and therefore vulnerability.

Distribution of diseases as well as insect pests is favoured by increased international trade and movement of plant materials. A wealth of experience and systems are in place to face this challenge. However, problems posed by intensified movement of plant materials are also increased by changes of climatic conditions. Exclusion of quarantine pests through regulatory means may become more difficult for authorities to manage as unexpected organisms may appear more frequently on imported crops.

A report presented by Brasier (2010) at CPM5 of the International Plant Protection Convention argues that current sanitary and phytosanitary (SPS) protocols are not appropriate in global market conditions, possibly also due to climate change conditions, and need some revision. *Phytophthora* spp., reported to be one of the most damaging genus among plant pathogens (such as potato blight), threatening natural forests and fruit trees, are increasingly transmitted via international trade and spreading worldwide through local adaptation and development of new species by hybridization. Pest risk assessment (PRA) procedures should be adapted for new conditions including consideration of climate change. Moreover, deeper knowledge at the local level, including by nursery operators, is proposed as a better solution to identify and to avoid the spread of diseases from the point of source in support of better diagnostics at the port of entry. Again, a more responsible and informed discussion on recent developments, including aspects of climate change, involving all relevant stakeholders and not limited to scientists and regulators, would address this problem more effectively in the future.

**Weeds**: Climate change induces changes in plant-growth-determining factors such as temperature and solar radiation. It also affects availability of growth-limiting factors (e.g. water) to plants and modifies the interaction between plants and growth-reducing factors such as insect pests. Beneficial insects foraging on weeds are also affected by climate change. Altogether, climate change may favour the spread of many weed species into new areas. This is illustrated by the examples reported below.

Red rice, a weedy relative of cultivated rice, can constrain production of rice grown for food. It has been reported that elevated $CO_2$ levels increased growth in both types of rice but more so in red rice. Aggressive weeds such as cheatgrass (*Bromus tectorum*) and Canada thistle (*Cirsium arvense*) flourish when $CO_2$ levels rise.

In India, *Prosopis juliflora* has invaded nearly 5.55 million hectares of land, constituting 1.8 percent of the geographical area of the country. The most potential invasive feature of the species is typically a greater assimilate partitioning towards roots leading to extraordinary enlargement in root mass with rich food reserves. This aids rapid and robust regeneration after mechanical lopping or after revival of ecological stress conditions such as drought or inundation. The increase in root biomass largely contributes to the weed's ability to tolerate climatic extremes such as peak summer associated with high temperatures and water scarcity, and peak monsoon winter with water inundation and flooding (Kathiresan, 2006).

*Solanum elaeagnifolium*, commonly called silverleaf nightshade, has been introduced from North America to Africa, Asia, Australia, Europe and South America, where it is an important weed of croplands and pastures. The invasiveness is aggravated by high seed production and an extensive root system that promotes vegetative multiplication and renders conventional control methods very difficult. Other negative effects include hindering commercial cropping activities, harbouring agricultural pests, being toxic to livestock and reducing land values. The plant is officially declared as a noxious weed in several countries. This weed prefers high summer temperatures and lower annual rainfall (Heap, Honan and Smith, 1997). Lower temperatures and high rainfall are the limiting factors that restrict range expansion (Heap and Carter, 1999). While the weed is drought and saline tolerant, it is highly sensitive to waterlogging and frost. Accordingly, increasing temperatures, alternating periods of soil moisture deficit and surplus periods in the semi-arid tropics caused by climate change could prove to be an inducing factor for invasive behaviour of *S. elaeagnifolium.*

As illustrated above, climate change will favour the spread of a number of invasive plant species, especially in a context where globalization of trade and exchange of germplasm worldwide represent pathways of introduction of exotic species. To cope with this new threat, vigilance is needed at community, national, regional and international levels. At a community level, vigilance is needed to detect and report emerging weed problems related to climate change and design appropriate management strategies. At a national level, enabling policy and institutional environments must be created to promote integrated weed management options at the community level. At regional and international levels, common regulations and strategic frameworks are needed to limit the impact of invasive plants.

## SEED SYSTEMS FOR QUICK RESPONSES TO STRESSES

Seeds are a core resource of crop production systems, and carry the genetic potential for crop adaptation to changing environments. The increased abiotic and biotic stresses that have been previously mentioned (temperature, diseases, insects, salinity, etc.) will directly impact food production. The system that will provide adapted varieties to farmers has three parts: plant genetic resource (PGR) conservation and distribution, variety development and seed production and delivery. The stronger the links among these different parts, the better the whole system will function.

Conserved and improved materials need to be available for variety development to address abiotic and biotic stresses impacting on crops. New varieties have to be generated at a pace that meets changing demands and requirements. Timely delivery to farmers of suitably adapted materials, of the right quality and quantity, at an acceptable cost, is essential. To work well, the system needs an appropriate institutional framework as well as policies and practices that support its component parts and the links between them. The time required for developing and releasing new varieties is lengthy compared with the pace of environmental changes under pressure from climate change. Urgent action is therefore needed to ensure that a local genetic resource base, adequate capacities and effec-

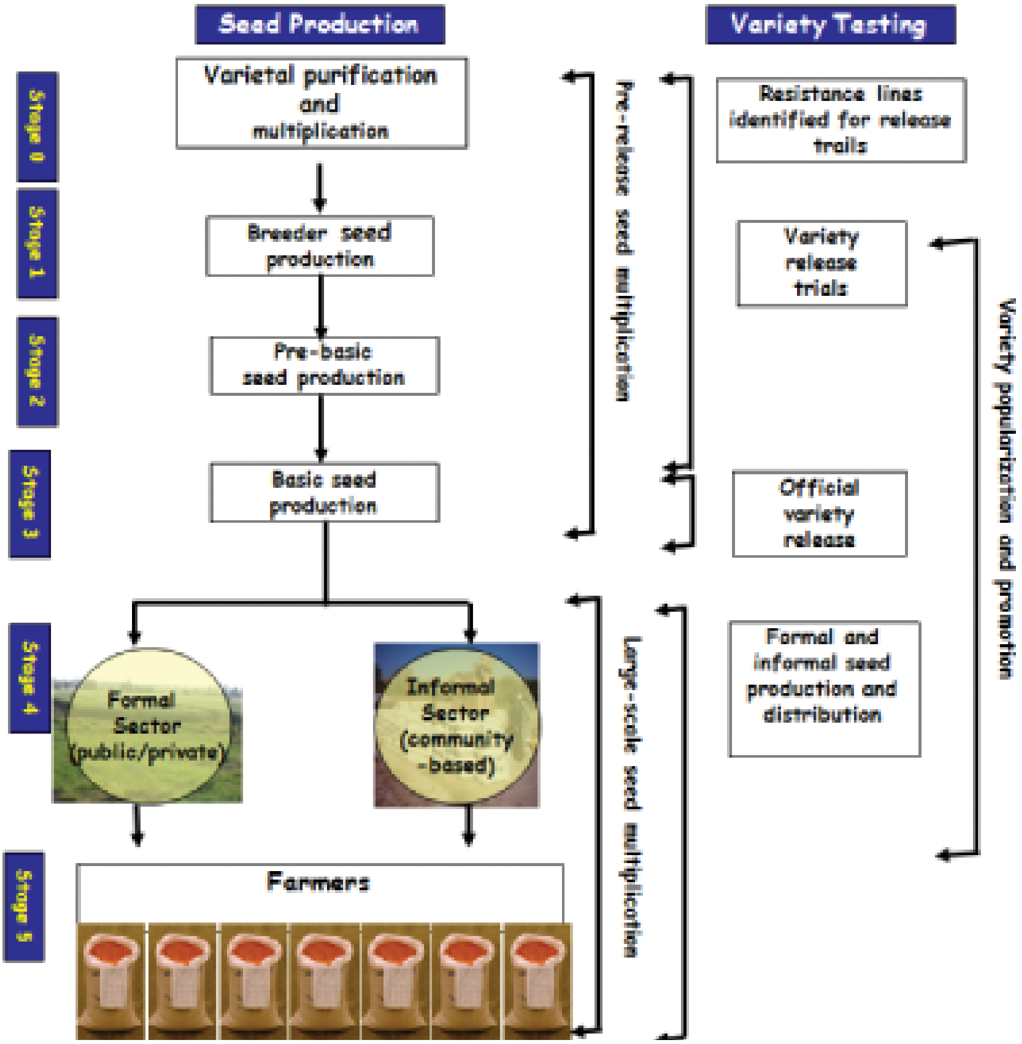

**Figure 2. Accelerated variety development scheme for wheat rust resistant varieties**

tive collaboration among policy, research and users are available for facing new needs. For example, the emergence and the diffusion of the new wheat rust strain UG99 has triggered an international initiative to develop and release rapidly new resistant varieties. Figure 2 shows an accelerated system whereby the seed multiplication activities start concurrently with variety release procedures being proposed in Ethiopia, with the objective of having seeds of new varieties available in farmers field in five to eight years.

Climate change will require an intensification of the **conservation of PGRs** *in situ* and *ex situ*. For example, the survival of crop wild relatives (an important source of genetic diversity for crop improvement) could be threatened. Simulations of climate change effects on wild relatives of groundnut (*Arachis*), potato (*Solanum*) and cowpea (*Vigna*) in Latin

America strongly affected all taxa, with an estimated 16–22 percent of these species predicted to become extinct and most species losing over 50 percent of their range size. While increased habitat conservation will be important to conserve most species, those that are predicted to undergo strong range size reductions should be a priority for collection and inclusion in genebanks (Jarvis, Lane and Hijmans, 2008).

Achieving adaptation to climate change will require **plant breeders to develop an increasingly diverse portfolio of varieties** of an extended range of crops. Generating these varieties will require sourcing heritable variations from the non-adapted materials that are not usually used by breeders, including crop wild relatives. Generating those intermediate materials to be used eventually in breeding would require pre-breeding, whereby germplasm curators and breeders work together to identify the carriers of sought-after traits, evaluate putative carriers and cross promising ones with elite lines to generate novel breeding materials. This will lead to larger populations of breeding materials that need to be cleared of deleterious alleles. This increased scope of work would necessitate more efficient genotyping and phenotyping platforms. There will also be a strong role for local institutions and communities to identify and select potential accessions more adaptable to climatic changes but also to local needs. Equally important attention should be given to existing materials with outstanding adaptation attributes including yield stability and nutritional values. To ensure that supply responds adequately to demand and hence ensures greater sustainability in the system, the crop and product preferences of farmers and other consumers should be taken into account. This demand-driven adaptation to climate change is not only a means of ensuring food and nutrition security but also of maintaining and improving plant genetic diversity including less profitable and neglected crop species.

**Developing seed delivery systems for local and improved varieties:** Seed systems are organized in different ways in different countries to ensure availability of new genetic materials, adapted to local needs, in particular changing environmental conditions. Seed systems can be very sophisticated or simple and local. Smallholder farmers around the world still rely heavily on informal seed systems (or farmer seed systems) and have little access to commercial seed systems. In some countries, well over 70 percent of seed, even of major crops, is managed within the farmer seed system. Both commercial and farmer seed systems will be essential in the distribution of climate change-adapted materials. The promotion of small-scale seed enterprises that can create the necessary link between research and local communities to bring genetic progress from test tube to the farmer's field is considered as a priority activity by the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture. For example, in northern Cameroon, local varieties of millet, sorghum and maize were not adapted to lower rainfall and increased drought. The agricultural research institute developed earlier maturing varieties of these crops and, with the support of FAO, farmer seed enterprises were organized to produce certified seed for sale to farmers in the surrounding villages. The new varieties produced good yields in spite of the unfavourable agro-ecology, and this has resulted in high demand and led to the creation of 68 community seed enterprises with over 1 000 members (both women and men) producing over 200 tonnes of seed per year. There are similar projects in other countries (Guei, Barra and Silué, 2011).

The discrepancies among seed regulations still remain a barrier to seed trade and exchange of varieties between countries. Climate change will impose more frequent extreme events that will increase pressure on seed security. Facilitating seed exchange among countries will be necessary to cope with situations of seed shortage in some countries. Harmonization of seed regulatory frameworks at the subregional and regional level will therefore be key to ease administrative procedures for cross-border seed trade. At the same time, the establishment of regional variety release procedures and variety catalogues will bring access to a wider diversity of varieties with the potential to adapt to climatic changes.

Agricultural diversification, crop and variety relocation based on mapping agro-ecological zones and variety characterization will be necessary to provide farmers with the germplasm (landraces and modern varieties) adapted to shifting agro-ecologies. Improved ways of transmitting information about crop variety adaptation through market and non-market channels are also needed.

## COPING WITH CHANGE: A LEARNING PROCESS

In the context of climate change it is essential to develop a new and deep understanding of the practical implications of changes occurring at local and national level. To achieve this, it is essential to enhance adaptive capacities of rural communities, researchers and national policy-makers, getting all these stakeholders better connected as changes occur.

In the past, rural communities have always been working to adapt to change in climate as it gradually occurred over centuries, but now changes appear to be faster and more dramatic. Therefore, farmers in their specific agricultural systems would benefit highly from support to help develop sound and location specific adaptation strategies. Farmers with knowledge of local ecosystems, and with critical thinking skills, would stand a much better chance of coping with the effects of climate change. In countries where participatory approaches such as Farmers Field Schools (FFS) have been piloted, attempts to adapt this methodology to the new challenge of climate change have been proposed. FFS curricula could be adapted to gather and analyse information on variability and effects of climate change, and devise and locally test coping strategies towards climate-resilient farming systems.

### Climate Field Schools

Following the successful experience of FFS on IPM – with a focus on field problems, starting with pests, developing field studies, using participatory methods and aiming to enhance resilience – a similar approach has been piloted in Indonesia to address new sources of variation, such as the effects of climate change. In recent years, climate change in Indonesia is increasingly a cause of concern, particularly with regard to variability in rainy seasons and rainfall intensity. Indicators of forthcoming rain – used by farmers based on local knowledge and traditions – refer to a lunar calendar (star position) and observation of falling leaves and singing birds. These signs were used as triggers to decide the appropriate planting time for rice crops.

In 2003–2007 Climate Field Schools (CFS) were established in Indonesia (Indramayu District, West Java) in collaboration with national institutions (Ministry of Agriculture, International Rice Research Institute, Indonesian Agency for Meteorology and Geophysics, Bogor Agricultural University, Asian Disaster Preparedness Center). This area is affected by drought and floods. Over 1 000 farmers worked in CFS with facilitators to understand seasonal climate forecasts as a basis for decision-making. It was intended to test coping strategies for local variations in water availability: time of planting, water capture and management, and adaption by multiple cropping. The main learning topics for the CFS were climate science, seasonal forecast and record rainfall for proper decision-making. Water management was at the core of the CFS curriculum and field studies. Critical factors emerged: local communities had limited power to adjust irrigation schemes to address water requirements, and choice of appropriate alternative crops was limited as rice remained the preferred crop for local farmers owing to reduced labour requirements compared with alternative crops. A lesson was learned showing that capacities addressed with CFS to understand and apply scientific climatological information, such as data collection and forecast interpretation, did not enable adaptive changes in management practices. Possibly a more systematic approach would have been required to mobilize collective action.

A similar experience was also conducted in mountain areas in the Andes (Bolivia, Peru and Ecuador) by the project Katalysis (Sherwood and Bentley, 2009). The overall approach and participatory training methodology built on the experience developed in these countries with FFS, aiming to cope with pest management and pesticide overuse. Also in this case, water management was the entry point for learning. Communities were suffering drought and floods at different times of the year. Learning processes focused on better observation, record keeping, developing storage methods such as increased soil organic matter or mulches, cover crops and water catchments, and testing alternative simple irrigation systems. From local field management, the attention then shifted to the watershed level: controlling goats and cattle, reforestation on slopes and windbreaks. This led to watershed 3-D maps on which management plans were built.

FAO has been working for over 20 years in developing FFS and other participatory approaches to assist farmers to gather and analyse agro-ecosystem information for better decision-making. Climate change becomes just a new entry point in the process of continuous innovation/adaptation of agriculture. Strengthening local knowledge and creative adaptation, supported by scientific insight, is a realistic way to help local institutions and farmers to adapt to climate change. This requires strong facilitators – therefore investment in human resource development on participatory approaches – and flexibility in programming and funding by national institutions/local government and international donors.

## CONCLUSIONS

Resilience is the ability of a system to cope with or return to balance after a stress and to regain the capacity to produce important services. Resilience is a fundamental feature of natural systems allowing them to cope with change. A number of factors pose a challenge to the continued resilience of ecosystems, including climate change. There is a need to restore and enhance resilience in agro-ecosystems, starting with an understanding of its essential features by those who make decisions, from the field to the national and global levels, which is an essential pre-requisite to management.

Understanding and managing local resilience in their own fields is the best option that farmers have to face changes and minimize vulnerabilities in their agricultural systems. At the same time, it is important that local and national institutions have a good understanding of resilience in production and food systems to support appropriate decisions on polices and research priorities.

Often the use of pesticides has been interpreted as an insurance against crop failures. During the 1960s and 1970s, the green revolution promoted input packages (fertilizers, pesticides, high-yielding varieties with narrow genetic base, etc.) to 'ensure' higher yields. This damaged agro-ecosystem resilience in several cases.

Crop intensification based on the indiscriminate use of chemical inputs resulted in major pest outbreaks in several crops. IPM emerged, with support from FAO, as a new approach to pest management. IPM requires a good understanding of local agro-ecosystems, from farmer to policy levels, to make decisions that respect ecological balance among populations of pests and their natural enemies, and to enhance system resilience.

Learning from previous experiences on coping with changes, and now facing new challenges, such as climate change, there is a need for a deep understanding of agricultural production from field to national and global levels, through a systematic approach.

Based on these experiences, it may be concluded that the synergy of challenges posed by climate change and intensification in agriculture, together with challenges posed by more frequent and intense global exchanges for increased trade and people movement, result in a demand for more concerted action among main stakeholders, both at local and global levels. This should be supported by a shift in thinking about scope and priorities to achieve sustainability in agricultural production, with a focus on stability and resilience of the agro-ecosystems.

It is urgent to understand local agro-ecosystems, their variability, modalities to develop and adapt new varieties and agricultural practices, while adjusting cropping systems. This is not only required to face the challenges posed by climate change, but also the combined effect resulting from all the drivers of change mentioned above. The essential role of national institutions, from policy to research and extension, in close collaboration with rural communities, should be recognized.

Innovative approaches should be used in agriculture, aiming not only to increase productivity expressed in tonnes/ha, but also to improve efficiencies in food production from the field agro-ecosystem – protecting resilience by enhancing ecosystem services – to the table and to national level, including social and environmental aspects, with support by adequate policies.

Similar principles would apply to seed systems and to pest management systems, aiming to achieve more resilient food production. Both these systems would benefit from a more coordinated action in crisis prevention, dealing with transboundary pests, pest outbreaks and effects of climate changes.

New learning processes and modalities for problem assessment and solving are essential at the level of farmers, extension, research and policy. At the same time, new partnerships and alliances need to be envisaged to connect main stakeholders, including farmers, at national and regional levels to address the new challenges. This may be achieved by working on experiences from field communities facing local variations to countries sharing similar problems, connecting them at regional levels, involving relevant institutions from research to extension to policy, ensuring their attention to the problems of food security at community level in a context of climatic change.

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# Building resilience for adaptation to climate change in the fisheries and aquaculture sector

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## INTRODUCTION

It is often overlooked that over 500 million people depend, directly or indirectly, on fisheries and aquaculture for their livelihoods. In addition, fish provide essential nutrition for over 4 billion people and at least 50 percent of animal protein and essential minerals to 400 million people in the poorest countries. Trade is also an important characteristic of the fisheries and aquaculture: fish products are among the most widely traded foods, with more than 37 percent by volume of world production traded internationally. But climate change is bringing an ocean of change to the world's fisheries, which are already in crisis from overfishing and poor management.

### Multiple drivers of change and the role of climate change

Change, whether positive or negative, is an integral part of fisheries and aquaculture systems and comprises those drivers that will impact the aquatic systems' biological processes through, for example, changes in water quantity and quality, temperature, salinity, oxygen, acidity, fishing pressure and natural habitats, as well as drivers of change that impact human choices in their use of aquatic resources, such as changes in governance structures, input and output prices, technological change, emergencies and cultural contexts. If not integrated into the management system, the impacts of these drivers of change may be profoundly negative on long-term sustainability – many capture fisheries worldwide have declined sharply in recent decades or have already collapsed from overfishing. Climate change will compound existing pressures on fisheries and aquaculture and the question of how to meet increasing demand for fish in the face of climate change poses a great challenge to fisheries and aquaculture management.

Since most aquatic animals are cold-blooded, their metabolic rates are strongly affected by environmental conditions, especially temperature.[1] Changes in temperature can have significant influence on the reproductive cycles of fish, including the speed at which they reach

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[1] Summary of expected impacts revised from FAO, 2009a – a review of scientific knowledge on climate change impacts and implications for fisheries and aquaculture.

sexual maturity, the timing of spawning and the size of the eggs they lay. The projected increasing temperatures will likely result in changes in distribution of both freshwater and marine species, with most marine species ranges being driven towards the poles, expanding the range of warmer-water species and contracting that of colder-water species. Examples of temperature-related impacts specific to aquaculture would be related to temperature comfort zones of farmed species and the increased spread of farmed fish diseases directly linked to increased temperatures. Whether positive or negative, these changes will have social and economic impacts on the fisheries and aquaculture industries and communities – possibly through new mismatches between where the fishing happens and where it is landed or processed, changes in farm profitability either through inputs needed or productivity of individual farms, or through the disappearance of traditional sources of local food and livelihood security. At the macro scale, there will likely be implications for international fisheries management owing to changes in the distribution of transboundary fish stocks, for example.

Greenhouse gas (GHG) accumulation is also increasing the acidification of oceans, with potentially severe consequences for shellfish and squid, mangroves, tropical coral reefs and cold-water corals. Among other services, coral reefs are home to 25 percent of all marine fish species, but changes in water chemistry may directly impact on their ability to produce their skeletons, directly impacting reef-based fisheries alongside tourism, medicine, etc.

**Rising sea levels** will displace brackish and fresh waters in river deltas, wiping out some freshwater aquaculture practices and destroying wetlands, but also creating new environments and some opportunities (e.g. for brackish aquaculture species). **Increased storm activity** (intensity and occurrence) endangers the lives of fishers, fishfarmers and coastal/riparian/lacustrine communities directly, can cause damage to fisheries and aquaculture infrastructure and housing, and presents additional threats for coral reefs and mangroves. More subtly, storms stir waters, causing temperatures and nutrients levels to change along the water column, having likely consequences for species distribution. Storms and floods will also increase the risks that farmed species escape, having potential impacts on farm profitability and genetic biodiversity in the natural systems.

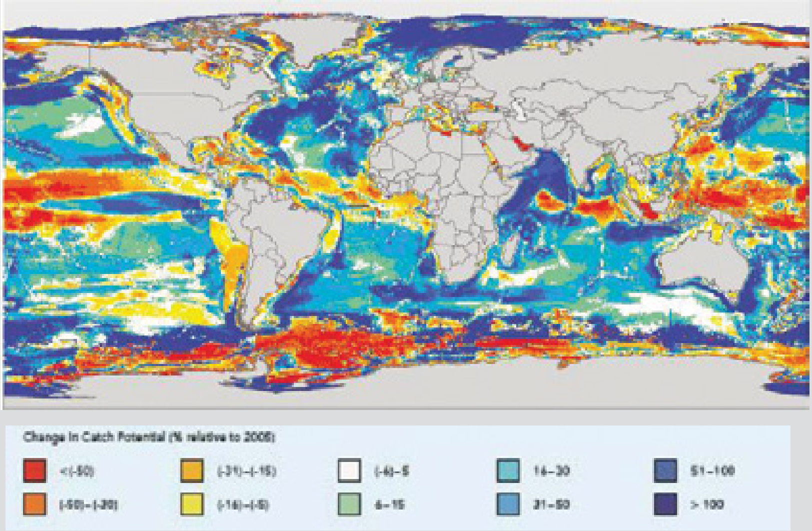
Fisheries- and aquaculture-dependent economies, coastal communities and fishers and fishfarmers are expected to experience the effects of climate change in a variety of ways. In addition to climate change impacts not stemming from the aquatic systems that they may face, such as increased risks of human diseases relating to increased temperatures, these communities are closely tied to changes in the aquatic world. These might include: displacement and migration of human populations from low-lying areas to less risky areas or to follow changes in fish distributions; effects on coastal communities and infrastructure due to sea level rise; and increased losses throughout the production and distribution chain owing to changes in the frequency, distribution or intensity of weather events. It must be noted that many fishing and coastal communities already subsist in precarious and vulnerable conditions because of poverty and rural underdevelopment, with their well-being often undermined by overexploitation of fishery resources and degraded ecosystems. As the vulnerability of fisheries and fishing communities depends not only on their exposure and sensitivity to change, but also on the often lacking ability of individuals or systems to anticipate and adapt, these communities tend to be among the most vulnerable.

BOX 1

### Predicted changes in fisheries catch potential

Results of a modelling exercise on the latitudinal shift in catch under different greenhouse gas concentrations scenarios indicate that there could be drastic changes, with the tropical countries suffering up to a 40 percent drop in catch potential and high-atitude regions enjoying as much as a 30 to 70 percent increase in catch potential.

**Change in maximum marine catch potential from 2005 to 2055 under the climate change scenario where greenhouse gas concentrations are doubled by the year 2100**



How would the current top fishing countries fare under this high emissions scenario? The model predicted that, by 2055, exclusive economic zones (EEZ) average catch potentials in Nordic countries (such as Norway, Greenland and Iceland) would increase by 18 to 45 percent; in the Alaska and Russia Pacific EEZ by around 20 percent, and decline by various degrees in most EEZ around the world, with Indonesia having the largest projected decline of the group – an over 20 percent decline across the 45 species currently targeted within its EEZ.

*Source*: Cheung *et al.* (2010).

In addition, as nations implement adaptation and GHG mitigation actions across all sectors, there may also be unplanned consequences (trade-offs and synergies) of actions in other sectors that drive changes within the aquatic food production systems. For example, national GHG mitigation efforts may include the development of aquatic renewable energy sources, such as through capturing energy in tides, currents, waves, wind, hydropower and aquatic biofuels. How these mitigation strategies impact the aquatic systems is not always

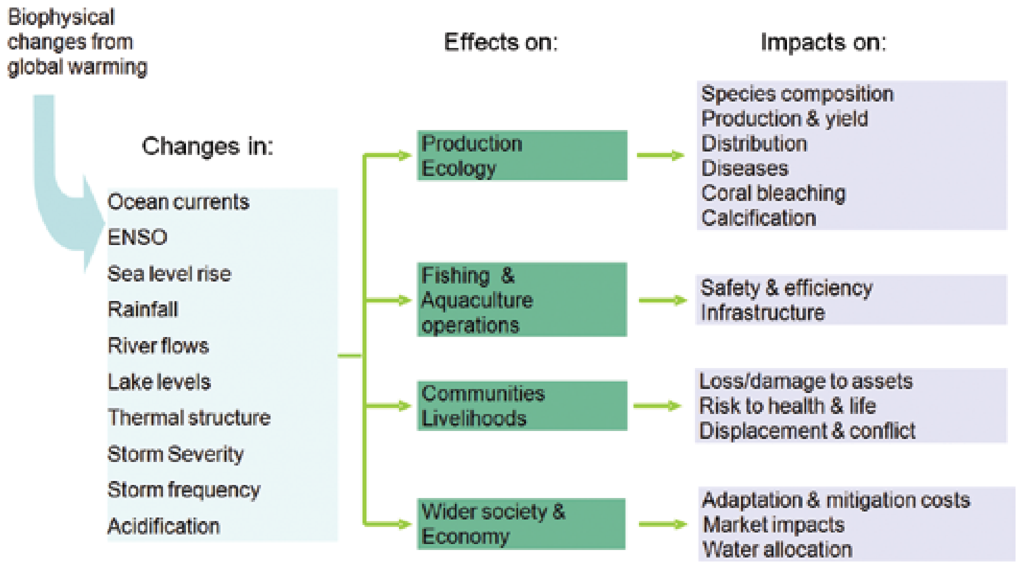


**Figure 1. Schematic representation of climate change impact pathways to fisheries and aquaculture systems**
*Source*: Badjeck *et al.* (2010).

well understood but, for example, the building of dams for hydropower could undermine fisheries and aquaculture systems downstream as water flows will be greatly altered. Drivers of change stemming from the need of other sectors to adapt to climate change will also arise. For example, agriculture production in areas faced with increasing water scarcity may need to divert water for irrigation purposes, impacting lake and river water levels and flows. In addition, the often open access nature of fisheries lends itself to being a planned or unplanned adaptation strategy for other sectors. For example, by 2007, 80 percent of conflict-affected refugees in the Democratic Republic of the Congo were successfully living from fishery and agriculture activities after receiving training in the new skill sets (UNHCR, 2007) and aquaculture is often looked to as a potential adaptation alternative for fisheries in the face of decline catches. From the unplanned side, “emergency fishing” is a common strategy for displaced persons (see FAO, 2007, for example). How these actions change, for example, water availability or quality and productivity or ecosystem functioning will need to be monitored and planned for.[2]

## VULNERABILITIES TO CHANGE

According to IPCC (2001), vulnerability to change is a function not only of the degree of exposure to climate change but also of the sensitivity of a system to changes in climate – “the degree to which a system will respond to a given change in climate, including beneficial and harmful effects” and adaptive capacity – “the degree to which adjustments in

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[2] See, for example, Leonhard, Stenberg and Stottrup (2011) for an assessment of impacts of offshore wind farming on fish communities.

practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate". Given that fisheries and aquaculture are part of a complex social-ecological system, there is no one set method for putting the IPCC vulnerability model into practice. The application of the IPCC model will depend on who's vulnerability is of interest for adaptation planning, at what scale is the adaptation planning to take place, as well as other pragmatic factors such as data availability. For example, Allison *et al.* (2009) were interested in the vulnerability of national economies to climate change implications to fisheries (see Box 2). Alternatively, one might be interested in the vulnerability of species, food webs or ecosystems (see Bell *et al.*, 2011 for examples of tuna, tuna food web, coral reef, mangroves, freshwater habitats and fisheries vulnerabilities in the tropical Pacific islands). Cinner *et al*. (2012) have applied the IPCC model to social-ecological coral reef-based fishing communities, imbedding the coral reef vulnerability to climate change into the fishing communities' vulnerability to changes stemming from within the coral reef systems.

Although adaptation planning can happen given a rapid appraisal approach to understanding vulnerabilities, the more detailed and in-depth the vulnerability analysis, the better targeted the adaptation planning. For example, recent community-level vulnerability work within 29 reef-dependent coastal communities across five western Indian Ocean countries showed large differences in adaptive capacities across the communities when facing the same climate change impact; requiring "nuanced" policy interventions to reduce vulnerability within each community (Cinner *et al.,* 2012). Within communities, there will also be vulnerability differences by age, gender and marginalized groups, so, ensuring that the vulnerability assessment includes these individuals will also provide better targeted adaptation planning.

What is interesting to note is that, even in the face of positive opportunities stemming from climate change, those vulnerable to change may not be able to take advantage of these potential benefits, whether it be, perhaps, because of lack of knowledge or access to new markets or overly rigid management system.

## PREPARING AND RESPONDING TO THE IMPACTS: ADAPTATION TO CLIMATE CHANGE THROUGH BROADER VULNERABILITY REDUCTION

Although determining a direct causal relationship between climate change and impacts on fisheries and aquaculture may not often be feasible owing to costs of research or complexity of the system under question, there is already much that can be done within a "no regrets" approach to reducing vulnerability. Fortunately, we are not without knowledge on how to build and maintain resilience[3] of the natural and human systems and, in the fisheries and aquaculture sector, there is no lack of guidance – the 1995 Code of Conduct for Responsible Fisheries (FAO, 1995) clearly demonstrates the principles and standards applicable to the conservation, management and development of the world's fisheries, including aquaculture, such as the prevention of overfishing, the minimization of negative impacts to aquatic

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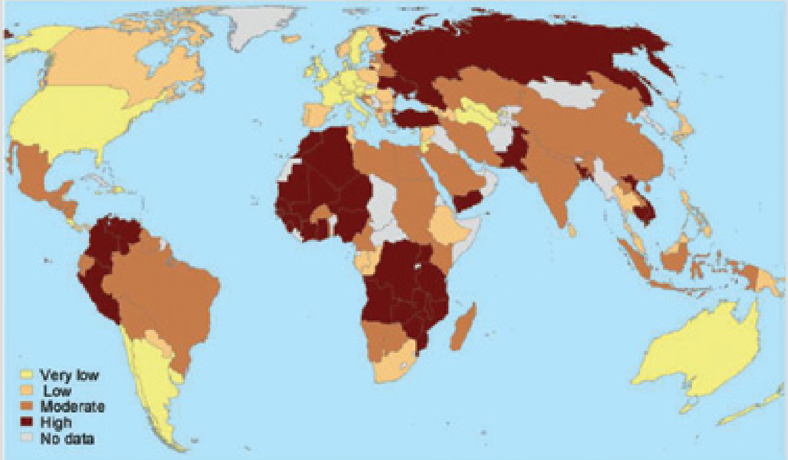
[3] Although the resilience concept is often limited to the ability of a system to "bounce back" to its previous state when faced with a shock, it is often the case that simply returning to the status quo is not enough and efforts to improve the ecological, social and economic well-being of the system before and after shocks must happen. Building back better is a term used in disaster risk management to reflect the need to not only respond to emergencies but to put in place disaster risk management that better prepares for the next potential emergency (http://www.preventionweb.net/files/13247_i0772e001.pdf).

BOX 2

### A global mapping of national economies' vulnerability to climate change impacts on fisheries

The first global attempts at defining national economies' vulnerability to the impacts of climate change on fisheries are represented below. Based on the IPCC definition of vulnerability and available data, national-level vulnerability indicators for the fisheries sector were calculated for 132 countries and relatively vulnerability rankings developed. The analysis revealed that 16 African least developed countries (LDC) and three Asian LDC were deemed to be among the relatively highly vulnerable countries. Unfortunately, data unavailability precluded many small island developing states from the analysis but, given their high dependence on fisheries, low adaptive capacity and high exposure to extreme events, one would expect high relative vulnerability rankings among these countries.



While many African marine coastal fisheries are not likely to face huge physical impacts, the region's adaptive capacity to respond to climate change is relatively low and fish consumption high, rendering communities there highly vulnerable even to minor changes in climate and temperature. In the northern hemisphere, the Russian Federation and Ukraine were ranked highly vulnerable owing to a predicted high degree of warming and a low adaptive capacity.

*Source*: Allison *et al.* (2009) and Daw *et al.* (2009).

ecosystems and local communities, and the protection of human rights to a secure and just livelihood. The ecosystem approach to fisheries and aquaculture (EAF/EAA) (see FAO 2003, 2009b; 2010). provides the approach, strategies and tools for implementing the Code and implies a holistic, integrated and participatory way to managing fisheries and aquaculture systems (see Box 3).

### BOX 3

### A brief overview of the ecosystem approach to fisheries and aquaculture

The EAF/EAA places its focus on fisheries and aquaculture management but broadens the perspective beyond seeing a fishery as simply "fish in the sea, people in boats" or an aquaculture farm as a disjointed fish production process, beyond consideration only of commercially important species, and beyond management efforts directed solely at the fish harvesting/farming process. EAF/EAA requires the inclusion of interactions between the core of the fishery – fish and fishers/fishfarmers – as well as other elements of the ecosystem and the human system (i.e. is a social-ecological system) and is aligned with the more general ecosystem approach but is focused on supporting the sector's participation in broader multisectoral application of the ecosystem approach:

> *The purpose of an EAF/EAA is to plan, develop and manage fisheries and aquaculture in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by the aquatic ecosystems.*
>
> *An ecosystem approach to fisheries (EAF) strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries.*

The EAF/EAA is the mechanism to attain sustainable development in fisheries and aquaculture – stressing holistic, integrated and participatory processes. Accordingly, application of the EAF/EAA should address the following principles:

- apply the precautionary approach when faced with uncertainty;
- use best available knowledge, whether scientific or traditional;
- acknowledge multiple objectives and values of ecosystem services;
- embrace adaptive management;
- broaden stakeholder participation;
- use the full suite of management measures;
- promote sectoral integration and interdisciplinarity.

*Sources*: FAO (2003; 2009b).

## USING EAF/EAA TO IDENTIFY KEY CLIMATE CHANGE ISSUES

As the EAF/EAA calls for a broader and more holistic approach to analysis and management actions, the EAF/EAA process itself assists in the monitoring of climate change impacts. A key step in any EAF/EAA process includes the identification of issues (and their prioritization through a risk assessment) that need to be addressed by management, including all direct and indirect impacts of the fishery/farm on the broader system. Included in this process is the identification of any non-fisheries/aquaculture issues (those that are external to the fisheries/aquaculture management system) that are affecting, or

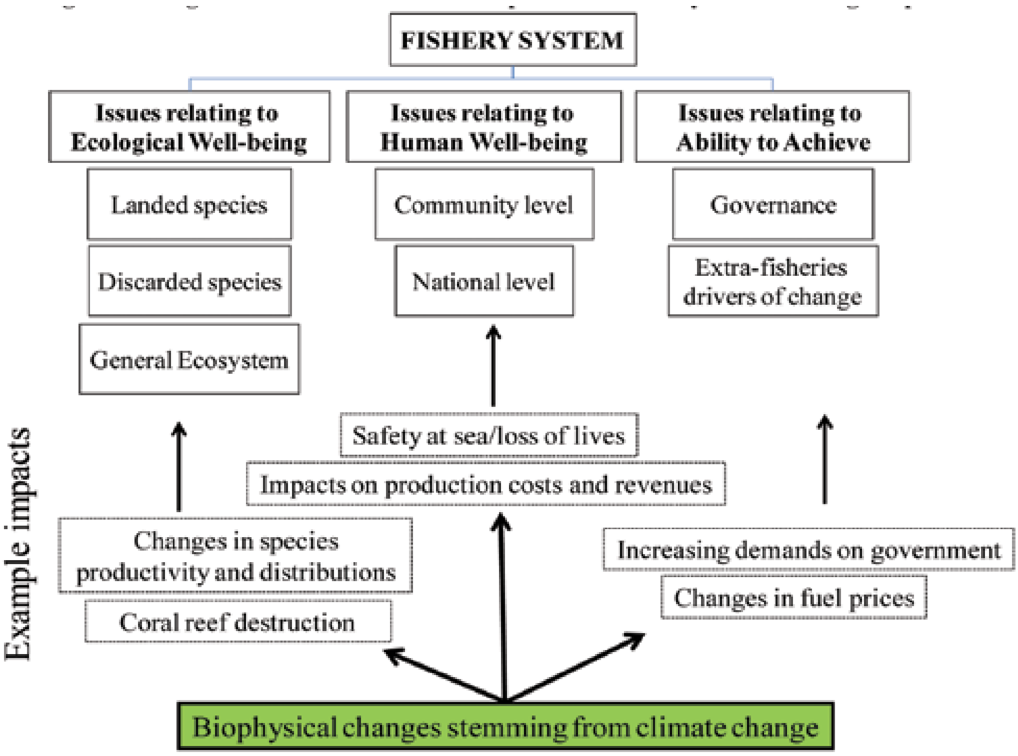


**Figure 2. Using the EAF issue identification process to identify climate change impacts**

could in the future affect, the performance of the system and its management such as climate variability and change (see Figure 2). Having the broadened and integrated monitoring system that an EAF/EAA would imply would allow for the monitoring of changes in the aquatic ecosystems and their impact pathways through the fisheries and aquaculture systems.

## USING EAF/EAA TO BUILD RESILIENCE TO CLIMATE CHANGE

To build resilience to the effects of climate change and to derive sustainable benefits, fisheries and aquaculture managers, as a top priority, need to adopt and adhere to best practices such as those described in the FAO Code of Conduct for Responsible Fisheries and the EAF/EAA. Progress in this direction would be an important contribution to maintaining biodiversity, preserving the resilience of human and aquatic systems to change, and improving our capacity to anticipate and adapt to inevitable climate induced changes in aquatic ecosystems and the related fisheries production systems. Some direct potential benefits of implementing the EAF/EAA include:

- creating resilient ecosystems, human, and governance communities through (i) decreasing the exposure of the sector by increasing the aquatic systems' resilience, (ii) decreasing the communities' sensitivities to change; as well as by (iii) increasing the sector's adaptive capacity;

- supporting intersectoral collaboration (e.g. integrating fisheries and aquaculture into national climate change adaptation and disaster risk management (DRM) strategies and supporting integrated resource management, such as integrated coastal zone or watershed management, water planning);
- promoting integrated monitoring and information systems - incorporating scientific and local knowledge sources;
- improving general awareness of climate change within and outside the sector;
- promoting context specific and community-based adaptation strategies;
- avoiding "mal-adaptations" (e.g. overly rigid fishing access regimes that inhibit fisher migrations, adaptation actions that would increase fishing effort in an over-fished fishery);
- embracing adaptive management, decision-making under uncertainty and the precautionary approach; and
- Promoting natural barriers and defenses rather than hard barriers that would impact the ecosystem.

Improving the general resilience of the fisheries and aquaculture system will reduce its vulnerability to climate change. For example, biodiversity rich systems are less sensitive to change than overfished and biodiversity-poor systems. Healthy coral reef and mangroves systems provide, inter alia, natural barriers to physical impacts. Fisheries and aquaculture-dependent communities with strong social systems and a portfolio of livelihood options have higher adaptive capacities and lower sensitivities to change. Larger-scale production systems under effective governance systems and having high capital mobility would tend to be more resilient to change.

In addition, by assisting in improving our understanding about the role of aquatic systems as natural carbon sinks and how fisheries impact this role, and by supporting a move to environmentally friendly and fuel-efficient fishing, aquaculture and post-harvest practices, implementing the EAF/EAA will also feed into global greenhouse gas mitigation efforts.

Interestingly, a recent modelling exercise (Merino *et al.*, 2012) to determine the capacity of the global fisheries and aquaculture sector to meet increasing demand for fish products while facing the high emissions scenario of the IPCC (A1B) concluded that meeting current and larger consumption rates is feasible but only if fish resources are managed sustainably and the animal feeds' industry reduces its reliance on wild fish. The authors note a strong caveat that ineffective fisheries management and rising fishmeal prices driven by greater demand could, however, compromise future aquaculture production and the availability of fish products. Putting into place robust and effective management now is the key to meeting future and uncertain challenges.

## PLANNED ADAPTATION

In addition to restoring and building up of the ecological system's natural resilience, the fisheries and aquaculture sector may also rely to a certain extent on risk spreading or reduction tactics, such as livelihood diversification, disease and disaster risk management, and creative combinations of public and private insurance tools. At a different scale, traditional policy and management planning and tools will need to be "climate proofed", such as by allowing spatial and temporal tools – protected areas and closed seasons, for example – to adapt to climatic variables or by explicitly incorporating decision- making under uncertainty into management plans. Management planning will need to evaluate, for example, how shifts from an open access situation towards defined and stable access rights might affect fishers' use of migration as an adaptation strategy when facing changes in species distributions.[4] At the regional level, regional agreements among countries sharing transboundary stocks will also need to be adjusted as shifts in stock distributions and changes in productivity occur.[5]

Technical innovation will also provide some adaptation options, such as the breeding of saline resistant aquaculture species to confront sea level rise, the development of storm resistant fish farming systems (e.g. sturdier fish cages) and the widespread use of information technology to share weather as well as market information. Fishing vessels of all sizes may be rendered more stable to allow for fishing further away from the coastal area to follow targeted species and resist inclement weather. Fish aggregating devices may be used to lure fish back within the traditional fishing grounds.

Proper aquaculture zoning mechanisms at the watershed level, biosecurity frameworks, risk analysis and strategic environmental assessments (FAO, 2009c) that take into account the added effects on aquaculture farms would enable the sector to better face potential threats such as new diseases, invasive species and eutrophication-related problems that can be exacerbated by climate change (e.g. increased water temperature and salinity).

Diversification within aquaculture, and especially exploring new opportunities in mariculture, potentially offers new adaptation options. By moving away from freshwater systems, both the impacts on water resources and the competition with other sectors for its use would be reduced. Further aquaculture movement off the coast and offshore can reduce impacts on coastal zone habitats and competition with other users (e.g. tourism) but a greater exposure to rougher seas would be a trade-off to such an adaptation action.

Tables 1 and 2 present examples of adaptation options available within fisheries and aquaculture, the choice of which would depend on the context at hand and the social, economic and ecological costs and benefits.

## CONCLUSIONS

Climate change is adding to the sense of urgency within fisheries and aquaculture for the need to improve the resilience of human and aquatic systems. The Code of Conduct for Responsible Fisheries and the Ecosystem Approach to Fisheries and Aquaculture provide many principles, strategies and tools that can be implemented today to lessen these social-ecological systems' exposure and sensitivity to climatic change as well as increasing their adaptive capacities.

Application of the EAF/EAA will help to ensure that effective stakeholder involvement in both monitoring changes and adaptation planning becomes the default approach to ensuring resilience of the socio-ecological systems and to minimize unintended

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[4] See, for example, Badjeck *et al.* (2009) for a review of institutions and management frameworks under climate change in Peru.

[5] See, for example, the proposal of Bell, Johnson and Hobday (2011) on ways to adjust an existing regional tuna fishing effort scheme in the face of climate change-related shifts in tuna distribution.

**Table 1: Example of adaptation to climate impacts on fisheries**

| Impact on fisheries | Potential adaptation measures |
|---|---|
| Reduced fisheries productivity and yields | Access higher value markets<br>Increase effort or fishing power* |
| Increased variability of yield | Diversify livelihood portfolio<br>Insurance schemes<br>Precautionary management for resilient ecosystems<br>Implementation of integrated and adaptive management |
| Change in distribution of fisheries | Private research and development and investments in technologies to predict migration routes and availability of commercial fish stocks*<br>Migration* |
| Reduced profitability | Reduce costs to increase efficiency<br>Diversify livelihoods<br>Exit the fishery for other livelihoods/investments |
| Increased vulnerability of coastal, riparian and floodplain communities and infrastructure to flooding, sea level and surges | Hard defences*<br>Managed retreat/accommodation<br>Rehabilitation and disaster response<br>Integrated coastal management<br>Infrastructure provision (e.g. protecting harbours and landing sites)<br>Early warning systems and education<br>Post-disaster recovery<br>Assisted migration |
| Increased risks associated with fishing (e.g. safety at sea) | Private insurance of capital equipment<br>Adjustments in insurance markets<br>Insurance underwriting<br>Weather warning system<br>Investment in improved vessel stability/safety<br>Compensation for impacts |
| Trade and market shocks | Diversification of markets and products<br>Information services for anticipation of price and market shocks |
| Displacement of population leading to influx of new fishers | Support for existing local management institutions |
| Various | Publicly available research and development |

*Adaptations to declining/variable yields that directly risk exacerbating overexploitation of fisheries by increasing fishing pressure or impacting habitats.
*Source:* Daw *et al.* (2009).

consequences of adaptation and mitigation actions. Integrated adaptation planning and implementation within a systems approach will not only allow for the specificity needed within each sector but also for addressing issues shared across sectors within a broader system.

We will need to continue efforts to improve and downscale our understanding of current vulnerabilities and adaptation strategies of the sector to prepare the sector for its own climate change planning and also to enable the sector to participate in national climate change planning, including providing feedback on the impacts of adaptation and mitigation actions from other sectors.

Technological innovation, public and private insurance schemes and disaster risk management will also provide necessary adaptation options but putting into place robust and effective management now will be the key to ensuring and enhancing the benefits derived from fisheries and aquaculture.

**Table 2: Example of adaptation to climate impacts on aquaculture**

| Impacts | Adaptive measures |
|---|---|
| Temperature rise above optimal range of tolerance | Better feeds; selective breeding for higher temperature tolerance |
| Temperature change increased growth rates; higher production | Increase feed input and better management |
| Eutrophication and upwelling; mortality of stock | Better planning: farm/cage siting conforming to ecosystem carrying capacity, regular monitoring |
| Increased virulence of dormant pathogens | None; monitoring to prevent health risks |
| Limitations on fishmeal & fish oil supplies/price | Fishmeal & fish oil replacement; new forms of feed management; shift to non-carnivorous commodities |
| Coral reef destruction | None; but shifting from harvesting to breeding of coral reef species may impact positively by reducing fishing pressure and harmful fishing practices; improving reef resilience |
| Salt water intrusion | Shift upstream stenohaline species- costly; new euryhaline species in old facilities |
| Loss of agricultural land | Provide alternative livelihoods- aquaculture: capacity building and infrastructure |
| Reduced catches from artisanal coastal fisheries; loss of income to fishers | Reduced feed supply; but encourages use of pellet feeds-higher cost/ environmentally less degrading |
| Increase of harmful algal blooms | Mortality and increased human health risks by eating cultured molluscs |
| Indirect influence on estuarine aquaculture through changes in brook stock and seed availability | None |
| Impact on calcareous shell formation/ deposition | None |
| Limitations for water abstraction | Improve efficacy of water usage; encourage non-consumptive water use aquaculture, e.g. cage-based aquaculture and/or mariculture |
| Water retention period reduced | Use of fast growing fish species; increase efficacy of water-sharing with primary users e.g. irrigation of rice paddy |
| Availability of wild seed stocks reduced/period changed | Shift to artificially propagated seed; extra cost |
| Destruction of facilities; loss of stock; loss of business; mass scale escapement with the potential to impacts on biodiversity | Encourage uptake of individual/cluster insurance; improve design to minimize mass escapement; encourage use of indigenous species to minimize impacts on biodiversity |

*Source:* De Silva and Soto (2009).

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# Building resilience for adaptation to climate change through sustainable forest management

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## INTRODUCTION

There are many and varied drivers of deforestation and causes of forest degradation around the world. Among others, these include conversion to other land uses (mainly agriculture), overharvesting of wood and non-wood forest products, poor timber harvesting practices, overgrazing, pest and disease outbreaks, invasive species and wild fires. Underlying drivers vary from place to place, including government policies that drive land-use changes, market forces altering demand for forest products, poverty and food insecurity, unclear or insecure land or resource tenure, among others. Climate change, and in some cases climate change responses, are adding to the existing stresses on forests.

The risks that climate change and variability pose to forests and trees are well recognized. Negative impacts are apparent in many places. Although it is often difficult to separate climate change from other stresses, evidence shows that in various places climate change is contributing to decreased productivity and dieback of trees from drought and temperature stress, increased wind and water erosion, increased storm damage, increased frequency of forest fires, pest and disease outbreaks, landslides and avalanches, changes in ranges of forest plants and animals, innundation and flood damage, saltwater intrusion and sea level rise, and damage from coastal storms.

Climate change and cliamate variability are threatening the delivery of a range of crucial goods (wood and non-wood) and environmental services from forests on which an estimated 1.6 billion people fully or partly depend. Forests' and trees' roles are varied, including, among other things, delivering clean and reliable water supply, protecting against landslides, erosion and land degradation, providing or enhancing the habitat of aquatic and terrestrial animals, providing a range of products for household use or sale, and providing employment. Given that forest resources directly contribute to more than 1 billion of the 1.2 billion people living in extreme poverty (World Bank, 2002), climate change impacts on forests can be expected to hit the poorest the hardest, thus making already vulnerable people even more so. Successfully addressing the negative impacts of climate change on forests and forest dependent people will be crucial to making progress towards sustainable development goals.

## WHAT CONSTITUTES ACTIONS TO BUILD RESILIENCE IN THE FOREST SECTOR

The word "resilience" is used here to encompass the following attributes of a system: the ability **to cope** with stress (also called "resistance"), the capacity **to recover** from the effects of disturbance and the capability **to adapt** to stress and change.[1]

Building resilience in the context of the forestry sector includes adjusting forest management to build resilience of forests and trees to the negative impacts of climate change, to increase the resilience of vulnerable people and to help build and maintain resilient landscapes.

Building resilience in the forest sector also requires efforts to ensure that adequate technical knowledge and expertise, an enabling policy and legal framework, responsive and effective institutions and governance mechanisms that can support timely, appropriate and equitable decision-making and action at local level are all in place.

## THE ROLE OF SUSTAINABLE FOREST MANAGEMENT IN BUILDING CLIMATE CHANGE RESILIENCE

Sustainable forest management (SFM) is an overarching goal for the forestry sector, applicable at international, national and subnational levels. The concept of SFM recognizes that forests have important economic, environmental, social and cultural values and that the appropriate balance of these should be sought in each country, reflecting the countries' particular goals, needs and circumstances.

The most widely intergovernmentally agreed language on SFM was agreed and included in a resolution of the UN General Assembly[2] in December 2007 and reads as follows:

> *"Sustainable forest management as a dynamic and evolving concept aims to maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations."*

The resolution further specifies that countries should develop or update and implement national forest programmes (NFPs) and other strategies for sustainable forest management. Furthermore, it lists seven thematic elements of SFM: (i) extent of forest resources; (ii) forest biological diversity; (iii) forest health and vitality; (iv) productive functions of forest resources; (v) protective functions of forest resources; (vi) socio-economic functions of forests; and (vii) legal, policy and institutional framework.

These specifications are important because the thematic elements define the scope of SFM, and the endorsement of NFPs identifies a credible approach for defining what constitutes SFM in a country and what is needed to achieve it. The principles of NFP processes are as follows: national sovereignty and country leadership; consistency within and integration beyond the forest sector; and participation and partnership. A country's NFP process helps it define its goals for SFM and policies to achieve it, using a

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[1] This is consistent with the definition given by the Second Assessment Report of the Intergovernmental Panel on Climate Change, which speaks of the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

[2] See UN Resolution 62/98 on establishing a non-legally binding instrument on all types of forests: http://daccessdds.un.org/doc/UNDOC/GEN/N07/469/65/PDF/N0746965.pdf?OpenElement

participatory approach involving all stakeholders. As needs and conditions in the country evolve (including those driven by climate change), the NFP can be used to adapt the forest policy framework accordingly. In short, the NFP process is conducive to responsive and adaptive policy development and implementation, taking into consideration risks and impacts of climate change on forests and forest dependent people.

Since the concept of SFM was reflected in the Forest Principles adopted at the Earth Summit in Rio in 1992, it has been made operational through regional and international criteria and indicator processes for SFM, actions agreed by the United Nations Forum on Forests (UNFF) and its predecessors,[3] and various regional policy processes on forests (e.g. the Central Africa Forests Commission – COMIFAC, and an effort currently under way to develop a legally binding agreement on forests in Europe), among others. A wide range of technical materials and best practice guidance have been developed to support the implementation of sustainable forest management on the ground. Forest certification systems for production forests have been developed and the area of forests certified to be under sustainable management continues to grow. Many countries are engaged in forest law enforcement and governance processes that support and provide incentives for SFM through trade measures. Overall, various indicators of sustainable forest management show that progress is being made in tropical countries and at global scale (FAO, 2010; ITTO, 2011). In short, SFM represents a broad goal for the forest sector, the achievement of which is facilitated on the ground by the application of best practices for the sustainable management of forests.

It was with this definition of SFM and with the supporting approaches, partnerships and tools in mind that the 14 members of the Collaborative Partnership on Forests (CPF) recognized that "sustainable forest management provides an effective framework for forest-based climate change mitigation and adaptation" (CPF, 2008). This includes building resilience to climate change and climate variability.

## BUILDING RESILIENCE OF FORESTS AND TREES TO CHANGING CLIMATE THROUGH FOREST MANAGEMENT

### Management measures

Some key strategies for increasing resilience of forests and trees to climate change through management of forests include the following:

- maintaining healthy forest ecosystems for resilience;
- restoring degraded forests;
- conserving, enhancing and using biodiversity.

These strategies can help both to enable autonomous adaptation, whereby ecosystem adjustments are made spontaneously, and facilitate planned adaptation, which requires human intervention.

### Maintaining healthy forest ecosystems for resilience

Maintaining forest ecosytems in a healthy state is the most straight-forward action to retain their resilience. Healthy forests are better able to cope with stress, recover from damage

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[3] Intergovernmental Panel on Forests and Intergovernmental Forum on Forests.

and adapt autonomously to change. Healthy ecosystems are more resilient to negative biotic and abiotic influences than are ecosystems under stress whose ecological processes are impaired. Enacting policies that create positive incentives, removing perverse incentives that act as barriers to sound forest and tree management and employing best practices in forest management will help maintain forests in a healthy state. Best practices include integrated pest management, disease control, forest fire management, employment of reduced impact logging (RIL) in production forests, limitation of gathering of non-wood forest products or livestock grazing in forests at sustainable levels, and forest law enforcement.

Removing constraints to implementing sound forest management may include dealing with financial constraints: too high absolute or up-front costs. It could mean improving monitoring systems to know where good practice is not being employed and why. There may be perverse incentives working against good forest management, or a lack of technical knowledge. The current spotlight cast on forests and on drivers of deforestation and forest degradation in conjunction with REDD+ (reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks) discussions under way in the United Nations Framework Convention on Climate Change (UNFCCC) can be expected to lead to a better understanding of the drivers of deforestation and forest degradation. Climate financing for adaptation and mitigation, through early action for REDD+ and also through the Green Climate Fund, could be expected to be helpful to countries'efforts to address the drivers of deforestation and forest degradation.

Concerning the constraints related to technical expertise, technical guidelines developed to support SFM, including some directly focused on climate change, could be helpful. Two organizations that have been particularly active in producing guidance documents are the Food and Agriculture Organization of the United Nations (FAO) and the International Tropical Timber Organization (ITTO). Among others, guidelines have been developed on codes of practice for forest harvesting, fire management, management of planted forests and sustainable management of dryland forests by FAO,4 and on sustainable management of natural tropical forest, restoration, management and rehabilitation of degraded and secondary tropical forests, conservation and sustainable use of biodiversity in tropical timber production forests (with the International Union for Conservation of Nature – IUCN), fire management in tropical forests, management of planted tropical forests by ITTO.5 FAO is working on guidance documents for forests and climate change, including integrating climate change into NFPs (FAO, 2011a), climate change for forest managers (FAO, in preparation [a]), and guidelines for building landscapes resilient to global changes in drylands (FAO, in preparation [b]). The recently released *Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security* are also directly relevant (FAO, 2012b).

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[4] See: http://www.fao.org/forestry/en/

[5] See: http://www.itto.int/policypapers_guidelines/

## Restoring degraded forests

Restoring degraded forests to healthy states, thereby re-establishing ecosystem functions, is a major strategy for increasing resilience. An estimated two billion hectares of land have the potential to be restored or reforested.6 Restoring the vast areas of degraded lands around the world would go a long way towards increasing the resilience of the world's forests. The Bonn Challenge, agreed at a ministerial conference held in Bonn in September 2011, calls for the restoration of 150 million hectares of lost forests or degraded lands by 2020.7 Undertaking restoration at an appropriate scale is essential. A case is made later in the paper for working at the landscape level. Landscape restoration covers a wide range of conservation, management and active restoration practices that strengthen the resilience, increase the quality and diversity of land resources, and provide additional socio-economic and environmental benefits in large territorial units, such as in watersheds.

## Conserving, enhancing and using biodiversity

Biodiversity is a key factor underlying the resilience of forest ecosystems and trees to existing stresses and is a basic ingredient for building their adaptive capacity in the face of future stresses. Conserving, enhancing and using biodiversity in the landscape are important for resilience. Resilience to changing environmental conditions is influenced by the diversity of species, of genetic variability and, at the larger geographic scale, of forest communities and ecosystems . Thompson *et al.* (2009) highlight some actions that may be taken to maintain or increase resilience in forests through management and use of biodiversity, including the following:

- maintain genetic diversity in forest by avoiding [intensive] selection for harvesting of only certain trees based on site, growth, rate or form;
- maintain stand and landscape structural complexity;
- maintain conductivity across the landscape by reducing fragmentation, recovering lost habitats (forest types), expanding protected area network and establishing ecological corridors;
- maintain functional diversity and eliminate the conservation of diverse natural forests to monotypic or reduced-species plantations;
- control invasive species and reduce reliance on non-native species for afforestation and reforestation;
- manage plantation and semi-natural forests – in a way that recognizes and plans for predicted future climate (e.g. assisted natural regeneration using provences from areas with climates approximating anticipated future climate);
- maintain biodiversity at all scales (stand, landscape, bioregional) and all elements (genes, species and communities) – and particularly populations that represent pre-adapted gene pools for responding to climate change.

Table 1 provides examples of forest management measures consistent with those mentioned above to increase forest resilience. A more complete set of management options

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[6] See: *A world of opportunity for forest restoration* http://pdf.wri.org/world_of_opportunity_brochure_2011-09.pdf

[7] See: http://www.ideastransformlandscapes.org/

**Table 1: Examples of measures to increase forest resilience to various impacts of climate change**

| Risks/impacts | Implications (social, economic, environmental) | Response measures for risk reduction and increased resilience |
|---|---|---|
| Decreased forest vitality and productivity | Reduced revenue from wood and non-wood forest products; reduced forest ecosystem services | Adjust silvicultural practices, change composition of species and varieties; increase forest biodiversity; implement forest restoration measures |
| Increased forest pests and diseases | Reduced forest revenue; reduced forest ecosystem services | Implement and Intensify pest and disease management measures; adjust silvicultural practices |
| Increased wildfires | Loss of life; damage to infrastructure; reduced forest revenue and ecosystem services; wildlife losses | Implement and Intensify wildfire management; adjust silvicultural practices |
| Increased water erosion and landslides | Damage to forest and to infrastructure (towns, roads, dams); reduced water quality | Undertake watershed management measures (including protecting and increasing vegetation cover; reducing intensities of harvesting and other uses) |
| Drought-induced forest/ tree dieback and land degradation | Reduced availability of forest products; increased wind damage; reduced grazing values | Plant windbreaks; maintain tree cover; change composition of species and varieties |
| Increased storm damage | Reduced forest revenue and ecosystem services; increased risk of pests and disease | Change species and adjust tree spacing to reduce risk; salvage harvesting; pest/disease control |
| Reduced extent and vitality of mangroves and coastal forests | Increased exposure of land to storm damage; reduced productivity of coastal fisheries | Increase protection, restoration and enhancement of mangroves and other coastal forests |
| Changes in species ranges and species extinctions | Reduced forest ecosystem functions; loss of forest biodiversity | Restore/increase forest connectivity and wildlife corridors; assist migration; take ex-situ conservation actions |

will be available in the upcoming publication, expected to be published in 2013, entitled *Climate change guidelines for forest managers* (FAO, in preparation [a]).

## Dealing with uncertainty

While broad regional and national patterns of climate change can be predicted with some certainty using climate models, making accurate predictions of the dimensions and character of changes at local level is problematic. The uncertainties associated with projections of climate change at local level, coupled with uncertainties about how impacts will reverberate in complex natural systems, make it difficult for resource managers to decide which adaptation actions would be most appropriate and cost effective to take. The fact that managers generally manage forest resources on medium- to long-term time cycles, in which their ability to make rapid changes is constrained, adds to the challenge. Measures that respond to expected trends in climate and that are consistent with sustainable forest management practices, represent ”no regrets” options (Seppälä, Buck and Katila, 2009). These are the logical starting point. Actions, for example, to reduce the risk and control against wildfires and pest outbreaks, where they exist, would convey benefits in any event, even if increased risks of climate change do not materialize.

Implementing best practices for forest management and implementing ”no regrets” options that will help forests cope with change and recover from disturbance will not be sufficient, however. Forest managers will need to take additional measures to increase the adaptive capacity of forests. Adaptive management is particularly relevant In environments where the future is uncertain (Robledo and Forner, 2005). Adaptive management involves a systematic process for continually adjusting and improving management practices by monitoring, analysing and learning from the outcomes (Seppälä, Buck and Katila, 2009). This process of observation, analysis, planning, implementing, monitoring and taking corrective action for further improvement is in itself a valuable adaptation tactic, particularly where the speed, direction and impacts of climate change are difficult to predict. Setting up systems for forest management conducive to adaptive management can help keep improvements in resilience in step with climate changes.

## CONFERING LIVELIHOOD RESILIENCE THROUGH SUSTAINABLE FOREST MANAGEMENT

Change, whether as a result of extreme events or more gradual change, is inherent in the human condition. People survive by adapting. Understanding traditional coping strategies and adaptation measures, and the role that social capital and local institutions play in facilitating adaptation, will help to formulate effective strategies for adaptation to climate change, climate variability and climate-induced extreme events.

Forests and trees play important roles in livelihood resilience in the face of climate change, including:

- as safety nets in times of emergency;
- as sources of products important for production and income diversification for farm household and rural families;
- as sources of employment (particularly important where farming and other rural livelihoods are no longer viable).

The importance of forests as safety nets in time of natural disasters (e.g. floods and droughts) or civil unrest is well documented (e.g. Angelsen and Wunder, 2003). During these times, forests are often relied upon to provide food for the household or products to sell for survival. They also fill gaps in other times of difficulty. While heightened dependence on forest foods and products generally drops off when times return to normal, it is important to keep the safety net option open (i.e. not restricting access of vulnerable people to forests when needed for survival), particularly where relief services and social services are not adequately developed to meet emergency needs.

Production and income diversification is a key strategy to spread risk and to help vulnerable rural people cope with environmental disruptions and economic downturns or shocks. This is a strategy widely seen in small farmer production systems with diverse crops, livestock and trees. In many places, the farmers' motivation for integrating trees into the farming system through agroforestry practices is income generation and diversification.

Small- and medium-sized forest enterprises have critical roles in local economies and helping alleviate poverty. Small- and medium-sized forest enterprises are estimated to make up more than 90 percent of forest enterprises and provide more than half of the forest sector employment in most countries (IIED, 2012). Together, they employ an estimated 20 million, a number that might be as high as 100 million if the informal sector, mainly in developing countries, were accounted for. A study on adaptive capacity and livelihood resilience in South Asia highlighted income diversification as a major coping strategy in response to flooding and drought; in several places farm households became increasingly involved in non-farm work, including woodworking and furniture making (Moench and Dixit, 2004).

The development of varied and effective coping mechanisms is prominent among people living in environments that are commonly subject to environmental stress. Arid zones provide a good illustration of this point. People living in arid zones have developed successful strategies to withstand drought and other climate and economic impacts. This adaptative knowledge and the skills of dryland peoples are key tools to cope with climate change. A wealth of examples are provided in the publications *Guidelines for building landscapes resilieint to global changes in drylands* (FAO, in preparation [b]) and *Highlands and drylands. Mountains, a source of resilience in arid regions* (FAO, 2011b).

Recognizing these coping strategies, providing policy support and incentives, and encouraging social networks and local governance structures that facilitate their perpetuation and further development are crucial for enhancing vulnerable people's resilience to climate change.

## BUILDING RESILIENCE AT LANDSCAPE LEVEL

Landscapes include the physical and biological features of an area as well as the institutions and people who influence it. The interconnectiveness of these factors underlines the value of working across sectors and addresses environmental, social and economic issues in an integrated way. The landscape is a useful unit on which to work in an integrated manner.

In most areas, forests and trees are embedded within a broader landscape influenced by a range of biophysical, social and institutional forces. Working at the landscape level is conducive to building resilience of land-use systems, natural resources and people's livelihoods in a cohesive way and supported by effective institutional and governance mechanisms. Managing forests within the context of a landscape approach is more likely to optimize their contributions to the stability and vitality of ecosystems and their ability to support societal needs in a sustainable manner. Understanding the dynamics between the different elements (biophysical, social, economic and institutional) and engaging local stakeholders in decisions will help in the development of strategies and actions to increase resilience.

Two examples of integrated approaches for managing forests and trees within a wider landscape context are provided below (taken from FAO, 2012a):

- Watershed management has been successfully used to restore and maintain the agro-ecological viability and production potential of various watersheds throughout the world, using land-use management techniques that integrate across sectors and also address socio-economic concerns of local populations. Decades of strong technical support and lessons learned in the process have led to increased awareness by decision-makers of the importance of supporting integrated watershed management programmes and projects that engage local stakeholders in participatory planning and management (FAO, 2006). Watershed management is also increasingly recognized as an appropriate approach in disaster risk management, particularly related to landslides, avalanches and floods.

- Fire management has recently undergone a transition away from a sector approach to a broader landscape approach, in which agriculture, forestry and rangeland concerns are considered simultaneously in order to better identify the causes and ultimately prevent destructive vegetative fires that often cross the boundaries of different land-use systems. An integrated approach of fire management supports building higher resilience and adaptive capacity of communities and ecosystems to the effects of vegetation fires.

Landscape approaches are also quite well developed in arid zones – such as the "gestion de terroirs" approach in West Africa, dating to the early 1990s, in which natural resource management at the village or community level links technical interventions, socio-economic factors and the legal and administrative functions. Sustainable land management for soil and water conservation is increasingly being planned and managed with the scale and principles of the landscape approach in mind. Sustainable mountain development and integrated coastal zone management are other examples of the landscape approach in action.

Political support for and the importance of cross-sectoral approaches at the landscape level is growing. Institutions, networks and partnerships have emerged in recent years aiming to improve rural livelihoods, land-use planning and management by adopting integrated approaches to land use. Examples include (FAO, 2012a):

- The Global Partnership on Forest and Landscape Restoration (GPFLR),[8] that aims to catalyse support for the restoration of forests and degraded lands to ensure that forests, trees and the functions that they provide are effectively restored, conserved and employed to help secure sustainable livelihoods and ecological integrity for the future.
- The International Model Forest Network (IMFN),[9] which supports the establishment of Model Forests, based on an approach that combines the social, cultural and economic needs of local communities with the long-term sustainability of large landscapes in which forests are an important component. By design they are voluntary, broad-based initiatives linking forestry, research, agriculture, mining, recreation, and other values and interests within a given landscape.
- The Landscapes for People, Food and Nature Initiative,[10] a collaborative three-year process of research, discussion, knowledge-sharing and advocacy that aims to develop action agendas for policy, investment, capacity building and research and to support their implementation through action and advocacy within UN conventions and key regional platforms.

In summary, adopting the landscape approach for planning and implementing climate change adaptation measures is a valid way forward. There is a body of knowledge, tools and partnerships that can be drawn upon to facilitate this.

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[8] http://www.ideastransformlandscapes.org/

[9] http://www.imfn.net

[10] http://www.landscapes.ecoagriculture.org/

## BUILDING FOREST-RELATED INSTITUTIONS AND GOVERNANCE MECHANISMS TO SUPPORT RESILIENCE

National institutions, policies and laws need to support actions to build resilience in the forestry sector at local level. Once an understanding is reached of the needs related to building resilience (of forests, trees and people), the institutional framework for forests and related sectors should be reviewed to see where adjustments are needed for the support of efforts to build resilience (FAO, 2011a).

In order to support landscape restoration, cross-sectoral coordination is essential. Agencies often work in relative isolation, and even at cross-purposes. This is at least partially due to the institutional structure and the lack of capacity of these institutions to cooperate closely in land-use planning and management (FAO, 2012a). There is a need – and real scope – for institutions dealing with ecosystem and land-use issues to integrate the management of natural resources (in particular forests, trees, soil and water) through improved, multisectoral land use.

The real action in building resilience, however, is on the ground. Building or reinforcing local governance mechanisms that engage local stakeholders is essential. These must exist to support appropriate and timely decision-making and action to develop and sustain resilient forest systems. They can provide the flexibility and responsiveness to react quickly and effectively to respond to climate change. Lessons from experience over the past decades have shown that forests can be well managed and degradation can be reversed by involving local communities, supported by legitimate decentralized institutional arrangements developed through consultative processes (FAO, in preparation [a]). There are many examples of farm foresters' producer groups (FAO and AgriCord, 2012) and community forestry groups (e.g. Nepal's Community Forest User Groups).

Social networks are also important components of local governance that can help provide for effective responses to climate change. Traditional forms of reciprocal and mutual work (e.g. in soil and water conservation work, in labour in shifting cultivation systems) have been partially or totally abandoned in many areas owing to social and economic changes (FAO, in preparation [a]). Encouraging the perpetuation or reactivation of these where appropriate for restoration work may be beneficial. Encouraging informal social networks for sharing information and experience on forests and trees may also help to build social resilience to climate change.

## CONCLUSIONS

Building climate change resilience around forests and trees entails a suite of actions. These include adapting the conservation, management and use of forests to reduce risk and confer resilience on forests and trees and on people vulnerable to the negative impacts of climate change. It requires building national and particularly local institutions that can support participatory and responsive decision making processes leading to equitable outcomes. Sustainable forest management provides a sound conceptual framework for building resilience. There is a body of knowledge and expertise, a number of well-tested approaches for integrated and landscape level planning and management, and a wide variety of tools available to assist with this work.

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# A comparative study of risk management in agriculture under climate change

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## SUMMARY OF THE PRESENTATION

This paper examines agricultural risk management policies and how these respond under conditions of climate change. It investigates the demand and effectiveness of different risk management policy tools using a microeconomic simulation model that is calibrated on different types of individual crop farms in three samples from Australia, Canada and Spain, which are affected in different ways by climate change. Four types of policies are analysed: individual yield insurance triggered by observed yield shocks on the farm; area yield insurance triggered by a reduction in the average yield in a given location; weather index insurance triggered by a rainfall index built from the nearest meteorological station; and *ex post* payments triggered by a large systemic shock.

Few insights into the impact of climate change on the variability of crop yields are provided in the available literature, although there is relatively more empirical information of its impacts on the level of yields. The impact of climate change differs depending on the location. For example, the most reliable sources to date reveal that climate change will increase production risk as measured by yield variability of the main crops in continental Spain, but that yield variability on the Canadian Prairies will likely be reduced for crops such as wheat and barley. In Australia, the evidence varies with some commodities showing increased production risk and others showing reduced risk.

As with any modelling work this analysis has its limitations: the samples of farms are not representative of their respective country or province, the climate change and behavioural scenarios are subject to strong uncertainties, the model only measures welfare gains for individual farmers, the number and representation of farmers' strategies and policy instruments are not exhaustive, and the value of the parameters could always be improved. The objective of this paper is not to deliver specific policy advice to the countries participating in the analysis. On the other hand this research does provide valuable insights about how policies interact with risk management and adaptation strategies, and how to tackle policy-making under strong uncertainties.

There are strong links between adaptation and risk management policies, and government responses to protect farmers from climate change risks will affect their strategies. For example, public support for insurance schemes and for *ex post* payments may reduce the

incentive to diversify farm production away from more climate sensitive crops and farm practices. In this sense these government supported instruments can potentially crowd out appropriate adaptation strategies by farmers.

Previous OECD work has shown that in general, insurance subsidies do not correct potential insurance market failures. This paper confirms that the gain for the farmer from lower risk is generally smaller than the budgetary cost of the measure. In this sense, these risk management policies are a second best response to reduce farm risk. This paper shows that, given an objective of reducing the variability of farm income, it is possible to investigate which is the most cost effective instrument under different scenarios, and then identify a policy that is robust across scenarios. In the absence of perfect and symmetric information, and thus the inability to implement first best policies, the analysis of these second best solutions can provide good guidance for policy-making.

The most reliable scenario of climate impacts only marginally changes the risk environment and, therefore, only marginally increases the demand for insurance (except in Spain). Individual yield insurance tends to be very costly for governments, while weather index insurance and *ex post* payments are cheaper on average. *Ex post* payments are highly variable and can be extremely high in some years. On the whole, however, climate change is likely to only slightly modify the yield variability in some locations and new risks associated with climate change do not seem to be an appropriate justification or basis on which to develop new risk management policies.

The analysis in this paper goes beyond a standard climate change scenario and investigates policy making under strong uncertainty. First, two different climate change scenarios are examined: standard climate change versus a situation with numerous extreme events. Second, three different behavioural responses by farmers are examined: no response due to ignoring climate change (misalignment); adaptation by diversification; and structural adaptation. The strong uncertainties about the climate change scenarios and behavioural responses (referred to as "ambiguities") are organized in seven scenarios. Additionally, two different policy objectives related to reducing farm income risk are investigated. Estimating the cost-effectiveness of each measure in each scenario is a complex quantitative exercise and the results are not always intuitive and differ across countries and farm types.

The possibility of extreme events and misalignment scenarios significantly changes the policy decision environment. The analysis of government's best response to this ambiguity is very challenging and requires a significant change in the approach. Rather than identifying optimal policies, the definition and understanding of the plausible scenarios is a core part of the analysis. Governments may seek the implementation of "robust" policies that are not optimal under any scenario but that may be able to respond well to different environments and avoid very bad outcomes, particularly under extreme events and misalignment. The misalignment scenarios are characterized by high budgetary expenditure and low adaptation practices. Other policy initiatives that focus on information and training can help prevent the misalignment of risk perceptions. This paper shows that it is technically feasible to define plausible scenarios and implement robust criteria in response to strong climate change uncertainties.

The first policy objective considered in this paper is the reduction of the overall risk of farm income. It is focused on normal, or marketable, risk and, therefore, there is not a strong case for public support unless it is temporary or oriented to developing insurance markets. It is known that reducing farmer's exposure to normal and marketable risks has crowding out effects on farmer's risk management and adaptation strategies. If a government retains the objective to reduce the overall risk, then area yield and weather index insurance are, in general, robust policy options: cheaper than individual yield insurance and covering a significant part of the farm specific risk.

The second possible objective considered in this paper is to provide an indemnity only when the lowest farm income outcomes occur. This objective is related more to catastrophic risk and the case for market failure and government support is stronger. *Ex post* payments can be effective in dealing with extreme systemic risk situation and are robust across scenarios. Individual yield insurance with the appropriate deductibles can also be better targeted to individual low returns than to overall risk, but it is commodity specific and more costly than other types of insurance.

*Ex post* payments have disadvantages that are not fully reflected in this analysis. The costs of assessing systemic losses may be significant; many countries also experience governance difficulties (such as those derived from moral hazard) in disciplining these *ex post* payments. Other existing social safety nets need to be considered as alternatives.

Insurance schemes offer a continuum from programmes that are individually triggered to those that are triggered based on specific indices. Area-based insurance is similar to individual yield insurance when fewer farmers are included in the area, and similar to an index insurance the larger the size of the area. The associated costs also run along a continuum and this is why there is no obvious best choice among these different instruments. A good alternative is to develop a range of instruments with limited government financial support so that individual farmers can self-select their insurance. Providing free *ex post* assistance in addition to subsidized insurance can hinder the effectiveness of these programmes.

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# The assessment of the socio-economic impacts of climate change at household level and policy implications

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## INTRODUCTION

The effects of gradual climate changes and extreme weather events in the recent past have undermined progress in the alleviation of poverty and food insecurity, while also having a negative effect on overall development efforts. Economic sectors that largely depend on weather conditions – either directly or indirectly – most notably agriculture and fisheries are increasingly subject to the impacts of climate change (IPCC, 2012). Moreover, the depletion of natural resources, as a result of increased environmental and demographic pressures, tends to aggravate the severity of climate change impacts. All in all, there are increasing concerns about the rising threats to current income and consumption patterns of households and individuals that earn their livelihoods from these sectors (Foresight, 2011; IPCC, 2012).

Evidence from global models indicates that farming populations residing in tropical (low latitude) regions are expected to experience deterioration in their agricultural yields and incomes. As a consequence, the incidence, depth and persistence of poverty and food insecurity will increase. Estimations for these regions suggest that yield losses for maize, wheat and rice range between 5 and 20 percent, should local temperatures increase by 3 °C; yield levels may halve if temperatures increase by as much as 5 °C. Expected economic losses range between a little as 0.5 and as much as 23.5 percent of a country's gross domestic product (GDP). In temperate (higher latitude) regions, yields may actually increase or decrease slightly, translating into changes in GDP that range between small losses and gains of up to 13 percent (IPCC, 2007; Tol, 2009). Nelson *et al.* (2010) estimate climate change will increase the number of malnourished children from 8.5 to 10.3 percent over the baseline scenario.

Nonetheless, critical methodological and evidence gaps exist with regard to the downscaled assessment of the impacts at the household level (FAO, 2008a). These constraints limit our understanding of the channels through which climate-related changes and extreme events affect vulnerable households. This lack of understanding further reduces our ability to design and implement effective policy measures aimed at either assisting at-risk households to prevent or mitigate negative impacts of future shocks or implement other risk management strategies, such as adapting their livelihoods, or responding appropriately to the burden of future shocks.

In particular, the way to approximate the different patterns with which changes in climate and weather conditions impact the livelihoods of the households working in agriculture and fisheries or other affected groups, is frequently circumstantial. Any relevant framework that intends to downscale and assess the impact of climate changes and weather shocks at household level needs to properly recognize and correctly define the nature of usually interdependent changes and extreme events that hit different types of livelihoods. For instance, gradual changes in temperatures or precipitation have to be considered along with changes in the timing and length of rainfall seasons or the incidence of extreme weather shocks. The resolution of such identification issues is a critical step in order to fully understand the impact of extreme events and gradual changes in climate.

Critical knowledge gaps exist as well on how welfare losses (or potential benefits) from gradual or extreme climate events are distributed among households. Poor farmers, pastoralists or fisherfolk are usually considered as most threatened by the effects of climate changes and weather shocks on the basis of possible disruptions in the production process. Urban poor consumers are also threatened if food prices increase1 in order to reflect both the impact of climate changes or if the true cost of food is adjusted to reflect environmental concerns.

However, behind higher vulnerability to poverty or food insecurity resulting from adverse climate events, there is a range of factors that reveal the weaknesses of households to cope *ex post* or manage *ex ante* the events. These factors reflect households' lower adaptive capacity and higher susceptibility to the impacts of the events and refer to low levels of human and physical capital, insufficient access to assets and services (public or private), weak institutional structures, inexistent or inefficient social protection programmes and greater exposure to uncertainty in the physical and economic environment (Skoufias *et al.,* 2011).

The objective of the present paper is to assist in describing a framework that could be employed to assess the socio-economic impacts of weather shocks and climate changes on agricultural households and particularly farmers in developing countries. In the following sections the paper discusses: (i) a framework for the assessment of impacts resulting from climate changes and weather shocks in food security at household level; (ii) the use of two methodological tools that are able to assess the vulnerability to food insecurity as well as the resilience of farming households to the incidence of climate change and extreme events; (iii) preliminary evidence on the welfare losses measured by increases in poverty, food insecurity breakthroughs or health-related impacts as are discussed in this relatively nascent literature, and; (iv) an outline of key policy messages for successful adaptation options at household level and particularly for farmers. A final section summarizes the paper.

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[1] Price increases, however, signify a positive shock for agricultural producers and fisherfolk.

## CLIMATE CHANGE – WEATHER SHOCKS AND LIVELIHOODS IN AGRICULTURE (THE SOCIO-ECONOMIC PERSPECTIVE)

Projections indicate that changes in weather elements will not necessarily manifest themselves through slow changes, nor will they be uniform across different regions and agro-ecological zones. While it is expected that the frequency, duration and intensity of hot spells will increase (number of hot days, maximum and mean temperatures) in all parts of the world, the same is not expected to happen for rainfall precipitation.

Farming, pastoralist, fisheries and forestry sectors and the livelihoods therein are directly sensitive to climate variability and changes. Food security implications are expected to emerge in general as follows:

- Food production and supply at global and local levels:
  - benefits in temperate regions may offset losses in tropical areas (but global availability of food does not necessarily imply satisfaction of each of the food security pillars locally);
  - disruption in trade and distribution channels resulting from extreme weather events.
- The livelihoods of groups involved directly or indirectly with agricultural and fisheries production and trade are also threatened:
  - producer groups that are unable to adapt to climate change or cope with weather shocks;
  - upward price adjustments may benefit net producers of food that are integrated into markets but net consumers in urban or rural areas that are not somehow involved in agriculture and fisheries will be hurt.

The climate change elements considered in the Climate Change and Food Security (CCFS) framework affect biophysical factors (for instance, plant development) and agricultural management practices, as well as different capital items (infrastructure, productive assets, human capital including health) that directly or indirectly are employed in food systems (FAO, 2008a). A comprehensive assessment of the impacts on food security should monitor, as closely as data permit, climate change and weather elements such as:

- mean, maximum and minimum temperatures (related with that is the number of growing degree days of crops);
- gradual changes in precipitation:
  - frequency, duration and intensity of dry spells and droughts;
  - changes in the timing, duration, intensity and geographic location of rain and snowfall;
- the incidence, frequency and intensity of storms, floods, droughts or other extreme events;
- the seasonal variability of weather elements and changes in start/end of growing seasons;
- the $CO_2$ fertilization effect of increased greenhouse gas concentrations in the atmosphere.

So far, the frequency and intensity of extreme events, along with irregularities in seasonal weather patterns, influence food production, food distribution, food emergencies,

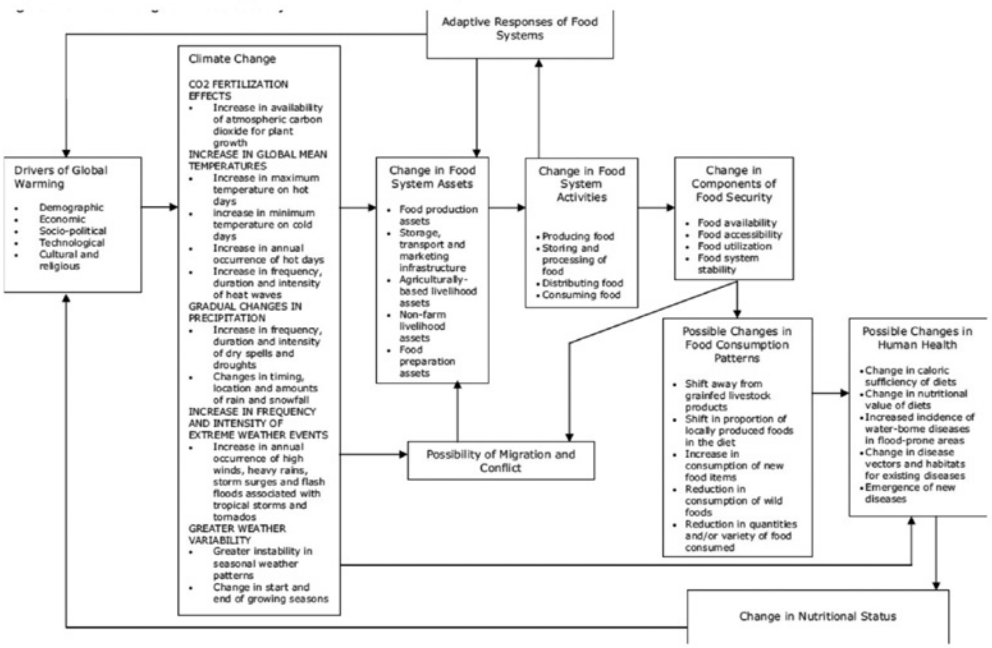

**Figure 1. Climate change and food security**
*Source*: FAO (2008a).

infrastructure, assets and human capital in rural and urban areas. In addition, the slow onset of climate changes will be evident in the properties of land for farming and pasture, forestry, fisheries, biodiversity and ecosystems.

Changes in climate are expected not only to change the average levels of key weather elements but also to increase their variability along with the frequency of weather shocks. The complex and diverse character by which climate changes manifest themselves requires multilevel approaches in studying their socio-economic impacts as well as the impacts on food security (Figure 1).

From the socio-economic point of view, a schematic approach to changes in the aforementioned weather elements is offered by Skoufias and Vinha (2012) and Figure 2. First, changes in the environment affect consumption of rural livelihoods through their impacts on agricultural production and income, since farm yields are directly affected by weather elements. *Ex ante* risk management and *ex post* shock-coping abilities of the household, respectively, may or may not be able to insulate or smooth consumption from income/yield effects. Given the income risk or shock, some reallocation of resources within the household is also likely to take place.

Second, health-related effects may also be expected, indirectly if food or other (e.g. health-related commodities) resources are downsized, or directly if changes in weather elements affect the prevalence of diseases or the level of the risk associated with the exposure to non-trivial weather changes.

The indirect (through income and resource availability and reallocation) or direct interplay between environment, on the one hand, and health and consumption, on the

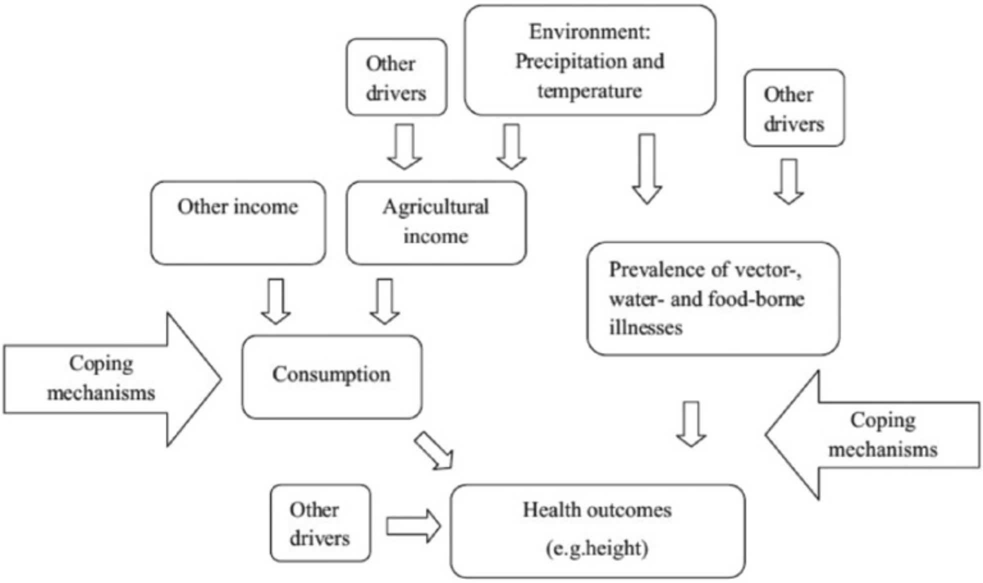

**Figure 2. The channels of impact of climatic variability on different dimensions of household welfare**
*Source*: Skoufias and Vinha (2012).

other, eventually determines the final welfare impact of climate changes locally in any time perspective. The evidence indicating that an environmental shock may have a positive indirect but a negative direct impact on health is noteworthy. For instance, Galindo (2009) shows that, in Mexico, the same increases in temperature or precipitation may benefit or damage crop yields depending on the region, the category of crops and the season in which they occur. While these changes increase yields in temperate climates, negative health effects have also been observed as breeding conditions for illnesses improved in tropical regions. Thus malnutrition and other health-related effects may appear, especially if an individual is already poorly nourished when the weather event occurs in the tropical regions of the country.

Nevertheless, increases in temperature and rainfall are shown to affect crop yields positively as long as those increases do not go out of the range that hinders the development of the plants. Other socio-economic characteristics such as age, the level of human capital and gender also influence the relative impacts of climate changes. For instance, it has been shown that a positive rainfall shock in India increases the survival probabilities of girls relative to the boys.

In developing countries, different groups are vulnerable to different types of climate events and the impacts those have impact on incomes and consumption (McMahon, Lipper and Karfakis, 2011). Accounting for loss of access to natural resources, production shortfalls, decreases in incomes and food price impacts, a rough grouping of affected types of households in developing countries includes (Figure 3):

- **Self-sufficient households without access to markets.** Subsistence farmers, herders, fishers and forest-dependent households that produce food for their own consump-

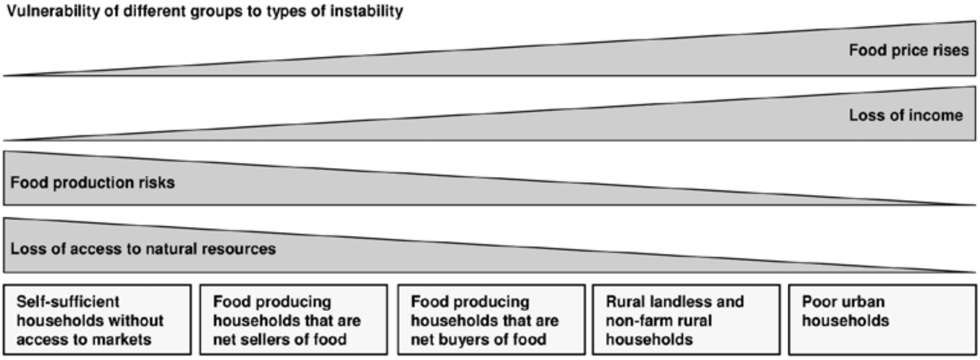

**Figure 3. Vulnerable population groups in view of multilevel risks**
*Source*: McMahon, Lipper and Karfakis (2011).

tion are subject to risks such as the loss of access to natural resources and to production shortfalls associated with climate variability effects. However, they represent a small number of people (in rural Malawi, 5 percent of all households do not buy or sell anything to the markets; in Nepal, this proportion increases to 8 percent; Karfakis *et al*., 2011b).

- **Food producing households that are net sellers of food.** Within rural economies there are households that produce and sell more food than they purchase. They are a significant group in developing countries (mainly in rural areas); an analysis of 12 low-income countries shows that, on average, 31 percent of rural households were net sellers of food (FAO, 2008b). These households are vulnerable to loss of access to natural resources, and to the variable productivity of their resources, but they may benefit from food price increases.
- **Food-producing households that are net buyers of food.** Most farming households in developing countries are both buyers and sellers of food. They are vulnerable both to production risks and to higher food prices. The interaction between these risks depends on the relative movement in prices of different agricultural commodities and on the extent to which these households rely on off-farm income.
- **Rural landless, non-farm rural and poor urban households.** Their food security depends on relative changes in incomes and in (local or global) food prices. As non-producers, they are not directly affected by production risks, although their employment prospects and incomes may be affected by the poor performance of the agriculture sector.

Across these groups, a gender dimension is also evident. Women and female-headed households are at risk, in both urban and rural areas. Either as food consumers or as food producers, female- headed households tend to have reduced access to assets (e.g. land and other physical or human capital), savings and credit (FAO, 2008b). As a result, women farmers typically achieve lower yields than men, which makes them more vulnerable to production and income shocks (FAO, 2011).

## METHODOLOGICAL TOOLS FOR (FARM) HOUSEHOLD VULNERABILITY AND RESILIENCE ANALYSIS

The concrete impact of the gradual onset or the sudden incidence of climate changes and shocks on different aspects of household food security or poverty is a field of study that presents relatively scarce evidence even nowadays. This is initially the outcome of knowledge gaps on the side of assessing how any shock affects the multidimensional and dynamic concept of food security and all of its pillars. On the other hand, however, knowledge gaps exist on the side of correctly identifying the type of the weather shock along with the channels through which climate changes are transmitted to household welfare of different household groups, as was described earlier.

Empirical evidence strongly indicates that food security is characterized by high volatility so much that stability in food security constitutes another of its pillars. As such, households and their members find it extremely difficult to obtain steady, adequate access to sufficient available food and to consume it (i.e. utilize) in the most efficient (and equitable between members) way. Thus, the World Food Summit defined food security as universal and permanent access to sufficient, safe and nutritious food (FAO, 1996).

Evidently, food security policies should try to accommodate both the assessment of households' current state of welfare and their expected access, availability and use of food. Therefore, minimizing the impacts of future food insecurity asks for policy-makers and households themselves to manage and adapt to the uncertainty and expected risks.

### Vulnerability to food insecurity analysis resulting from climate change

Vulnerability analysis is able to cope with some of these issues given its ability to provide a relatively more dynamic overview of household welfare. With the use of a household survey as minimum data requirements, an estimate of the probability for a household being food insecure in the near future can be computed. Vulnerability as a probability to become food insecure considers a measure of food security (usually, calorie intake or value of food consumed per capita or per equivalent adult units), as a function of:

- Household characteristics and specifically:
  - demographic features;
  - assets (physical, social, human capital or other);
  - income sources characteristics;
  - geography and others.
- Exposure to climate-change risks.
- Capacity to cope with weather shocks or other climate events.

The methodology works in two interdependent steps, employing multivariate analysis in both of them:

1. the direct impact of climate changes on agricultural productivity and farm income, is initially explored; and;
2. through this impact, the effect on food consumption and food security is assessed.

This tool eventually is able to provide an estimate of the distribution of expected food consumption and, along with the use of a predetermined food security threshold, the probability for each household to become food insecure. This probability, alongside the current food insecurity status of the household, enables the profile of food insecure households to be built more accurately, setting the pace for better-designed and targeted policies.

Through its forward-looking lens, vulnerability analysis allows important distinctions to be made between the food poor and/or vulnerable and the food non-poor and/or more resilient groups of the population. In this way, food-insecure but not-vulnerable households, being able to improve their situation without major external assistance (e.g. transitory food-insecure), are distinguished from those that are unlikely to improve their situation single-handedly (i.e. chronically food-insecure and vulnerable). As such, vulnerability analysis is able to strengthen the design of interventions, enhancing food security.

Vulnerability analysis also allows the explicit identification of climate change as a major risk and other factors that threaten food security of farmers. Hence, this analysis can assist in the design of safety nets – interventions that will help reduce these risks and/or improve risk management capacities. Vulnerability analysis is able to accommodate the multiple dimensions of food insecurity,[2] in terms of the asset base, flows of incomes, farming productivity, access to resources and services at the household or communal levels. Thus, the profiling of vulnerable groups is built on a more solid basis, improving the reliability of the safety net policies in terms of design and implementation.

In terms of policy, the relative effectiveness of different policy tools can also be evaluated through analysis that can simulate how quantifiable policy options on their own, or in conjunction with each other, can be used to reduce vulnerability to food insecurity of households affected by climate change or other risks. An exercise in Nicaragua indicates how policies that are associated with developmental outcomes (i.e. education), or improved agricultural practices (i.e. wider input use), reduce expected vulnerability to food insecurity, which is projected to increase significantly by 2030 as temperatures follow a steadily upward trend.

A literature review describing in some length how vulnerability analysis emerged as an analytical tool, assessing the food security status of households dynamically while explicitly accommodating risks and shocks, including concrete aspects of climate change, can be found in Karfakis *et al.* (2011a). The paper applies the methodology in the study of the impact of climate change on Nicaraguan farmers (the results of this exercise are discussed later in this paper). The review starts from Sen's work (Sen, 1983), who initiated economic research on poverty and welfare, acknowledging the importance of uncertainty and its implications for household welfare. It describes how the concept, initially introduced to natural sciences and finance, was adapted to poverty analysis by Ravallion (1988), Chaudhuri (2001), Chaudhuri, Jalan and Suryahadi (2002) and Christiaensen and Boisvert (2000) and references therein. In poverty analysis, vulnerability computes the probability that a welfare indicator (usually total consumption per capita) will fall below a predetermined threshold in the near future.

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[2] For instance, this analysis may provide some evidence of households locked in a poverty or food security trap. Exposure to risks and lack of capacity to handle the impact of shocks may enforce the choice of income-earning strategies with lower variance but also low mean earnings. Appropriate policy interventions employing social safety nets may be necessary in this case to reduce exposure to risk and uplift the household from the poverty trap.

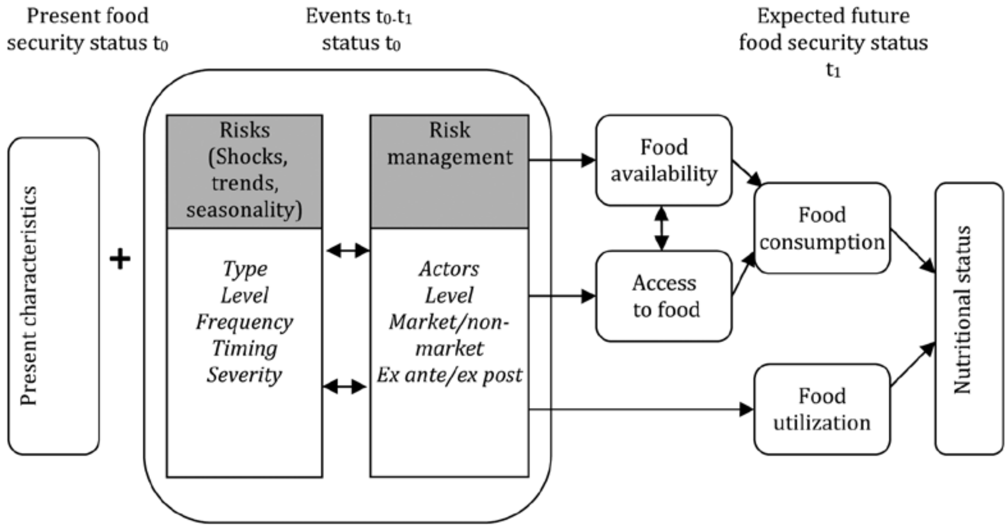

**Figure 4. A framework for analysing vulnerability to future food insecurity**
*Source*: Løvendal and Knowles (2005).

The conceptual framework for vulnerability to food insecurity resulting from changes in climate is based on the proposal of Løvendal and Knowles (2005). This framework (along with vulnerability to poverty analysis) is based on the Social Risk Management approach (Holzmann and Jørgensen, 2000). The framework sees vulnerability as the likelihood of being food insecure in the future and is a function of present characteristics, exposure to risks emerging from changes in climate and the characteristics of these risks, as well as the capacity of the households to manage or cope with them. In the context of climate change, the risks and their characteristics have to do with weather changes and climate shocks as described in the previous section. The framework is summarized in Figure 4.

## Resilience analysis as a tool to assess the impacts of climate change

FAO has also been testing resilience analysis (Alinovi *et al.*, 2009) to assess how households adjust their livelihoods after perturbations. Resilience is usually defined as the ability of groups or communities to cope with external stresses and disturbances resulting from social, political and environmental changes (Adger, 2000). In a food security context, however, resilience is defined as the ability of a household to keep at a certain level of well-being (i.e. be food secure) by withstanding shocks and stresses. This depends on available livelihood options and on how well households are able to handle risks. This definition implicitly considers both *ex ante* actions that reduce the risk of households becoming food insecure and *ex post* tools that help households cope after a crisis occurs.

The resilience tool provides a framework for understanding the most effective combination of short- and long-term strategies for moving families out of traps of poverty and undernutrition. The resilience framework tries to address the root causes of household vulnerability instead of trying to predict how well households will cope with future crises or disasters. The factors that make households resilient to food security shocks can

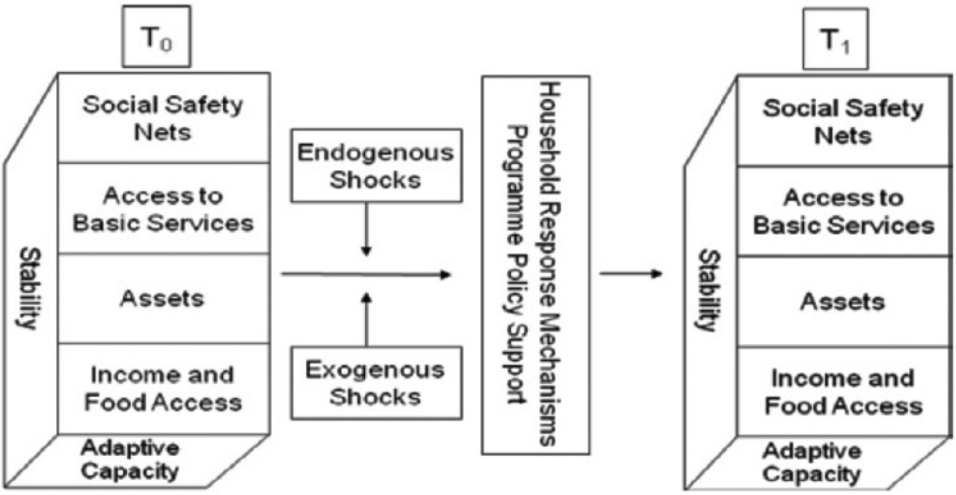

**Figure 5. A framework for analysing household resilience to food insecurity**
*Source*: FAO (2010).

be integrated into four basic pillars (Figure 5) that determine the stability and adaptive capacity of each one of them and include:

- income and access to food;
- assets such as land and livestock;
- social safety nets such as food assistance and social security;
- access to basic services such as water, health care and electricity.

Non-parametric analytical methods are employed to combine these factors into an index that gives a quantitative resilience score for each household. Further analysis indicates which pillar(s) of resilience need(s) to be strengthened to further build household resilience. The insight into why and how people become food insecure suggests ways of preventing this from happening. In a study for Nicaragua, Ciani (2011) showed how the resilience score of different household groups changed (declined) after the incidence of hurricane Mitch. If interventions are designed in ways that increase resilience by enhancing people's ability to manage risk, including climate-related events and shocks over time, then the need for humanitarian interventions when hazards occur will diminish.

In general terms, resilience and vulnerability analyses should not be seen as alternatives, but as complements. Vulnerability analysis tends to measure the susceptibility of people to damage when exposed to particular hazards or shocks. It often focuses on one specific target variable, usually represented by the household consumption expenditure (for food or total consumption). Both analytical tools use data available from national household budget surveys such as the Living Standard Measurement Surveys (LSMS) or Household Income and Expenditure Surveys (HIES).

By pinpointing the specific factors that make households resilient, the framework gives decision-makers clear indications of where to intervene. For example, resilience analysis in Palestine shows that there is a big difference in how households headed by women and those headed by men cope with shocks. Women have fewer assets and less access to different sources of income than men. Thus, households headed by women rely heavily on public services and social safety nets. A policy that further cuts safety nets and public services would thus have a severely negative impact on these women and their families.

## PRELIMINARY EVIDENCE FROM HOUSEHOLD LEVEL ANALYSIS OF CLIMATE CHANGE IMPACTS

Global or economy-wide models have been most frequently used to assess the impacts of climate change on the economy.[3] For example, Nordhaus (2010) and Olivieri, Rabassa and Skoufias (2010) estimate that projected aggregate impacts on poverty under the baseline scenario, under business as usual or an emission abatement path are marginal (even though GDP is projected to decline 1.5 percent by 2055). Such marginal effects are justified since mitigation policies (such as abatement policies) affect in principle the welfare of higher income regions and countries.

At subnational level, two major types of methods are employed to study the impacts of climate change.[4] The first strand of work tries to estimate how land rents (e.g. farmland revenues net of purchased input costs) would change in view of climate variability as well as other characteristics (economic conditions, soil quality, etc.). This type of analysis (usually called "the Ricardian approach") is based on the economic rationality that, when farmers maximize profits, land rents should reflect the net revenue value of farmland; in that case, changes in weather should be reflected in revenue changes as well. This approach in the context of climate change has been suggested by Mendelsohn, Nordhaus and Shaw (1994), and has been applied to India (Jacoby, Rabassa and Skoufias, 2011), Ethiopia (Deressa and Hassan, 2009), 11 African countries (Kurukulasuriya *et al.*, 2006) and possibly elsewhere.

A second strand of empirical research selects a welfare measure and explores the impact of climate changes on household welfare directly. This welfare measure may be a measure of household consumption or income, poverty or a health-related indicator. In the present review most attention is given to the second type of empirical evidence.

Heterogeneity in the adverse effects is the major message emerging from the type of models that try to assess the impact at sectoral level within a country through time or through household level analysis.[5] Either because of location, as a result of differentiated access to assets or the diverse structure of income sources (diversification) and expenditures, the welfare impact is different across household groups. For instance, it is estimated that agricultural output per hectare in Brazil may decline on average 18 percent by 2040, but impacts are positive in certain communities (up to +18 percent) and negative in others (up to –40 percent) (Assunção and Chein, 2009). Jacoby, Rabassa and Skoufias (2011) also show that heterogeneity is the major message with regard to the impact of climate changes on consumption in India. While average productivity may fall by about 13 percent in 2040,

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[3] At cross-country level, a wide range of research has been carried out on the impacts of climate change. The work by Lobell, Schlenker and Costa-Roberts (2011) on the negative impact of temperature increases on the yields of the major food crops (especially maize and wheat) since 1980 is noted here. Also Schlenker and Lobell (2010), using growing degree days to capture the impact of temperature increases, show that average yield losses in sub-Saharan Africa are expected to range around –22 percent for maize, –17 percent for sorghum and millet and –18 percent for groundnuts.

[4] Vulnerability analysis to some degree integrates both types of empirical approaches.

[5] Skoufias, Rabassa and Oliveri (2011) provide a thorough review of the evidence at cross-country and subnational levels.

rural and landless households are expected to see relatively small reductions in their per capita consumption (about 5 to 6 percent) as a result of increases in incomes and wage earnings from farm activities that will become more profitable after agricultural prices increase. These estimates, however, still suggest that poverty rates may increase (1 to 6 percent) and that climate changes hurt mainly the poor. In general, returns to land and wage labour are expected to decline and, especially for land, large-holders will be mostly hurt. Nevertheless, associated increases in the prices of crops will reduce, neutralize or even generate positive welfare effects for some households.

The results in India vary by household characteristics (e.g. land size) while some adaptation options (changes in production methods, in crop mix or other) are also accounted. In particular, market-based (or autonomous) adaptation strategies reduce welfare losses from –11 to –6 percent. Stronger adaptation strategies such as migration also reduce welfare losses; in Brazil poverty rates increase by only 2 percent if migration strategies are accounted for (3.2 percent otherwise).

Similar effects are found if changes in the variability of climate events are explored (instead of changes in average weather elements). In Indonesia (Skoufias, Essama-Nssah and Katayama, 2011), a decrease in rainfall in the 90-day period after the monsoon is associated with a 14 percent decline in per capita expenditures other than food. In the Philippines, climate variability, and in particular negative rainfall shocks, reduce household expenditures on food (Balisacan *et al.*, 2011).

Felkner, Tazhibayeva and Townsend (2009) employ a multistage plant development (for planting, growing and harvesting) and an economic model to study the impact of climate changes on rice yields and on income, respectively, for farmers in Southeast Asia. Climate impacts are considered with the use of two possible scenarios regarding changes from neutral to mild or high greenhouse gas emissions. One of the major results of this research suggests that, while yields decline significantly in both models, under both scenarios, for a significant proportion of the sampled farmers, household income is not affected apart from the case of farmers who experience absolute crop failures and are poor. This result indicates, according to the authors, the inability of poorer households to adapt.

Using vulnerability analysis, Karfakis *et al.* (2011a) analysed a sample of 1 242 farming households from Nicaragua. The authors used the daily per capita value of food consumption (an indicator approximating household food security) as a function of several variables representing households' demographic and social characteristics, asset holdings, liquidity constraints, access to infrastructure and geographical location. Along with a household's own capacity to cope with shocks or manage risks (through the use of own assets, farm inputs, participation in producers organizations, etc.), safety nets in the form of government and non-government assistance programmes are employed to account for the impact of social protection programmes. Climate changes are accounted as the proportion of temperature increase (or decrease) during the survey year relative to the long-run average temperature at the municipality level.

This analysis employs a model that studies the direct impact of temperature changes on agricultural productivity and farm income (direct impact) and, through this direct effect, the impact on food consumption and future food security. Despite social or household

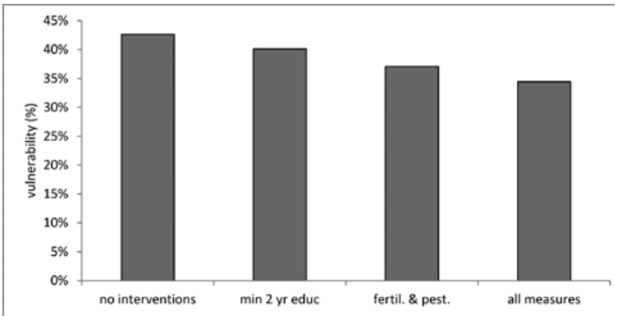

**Figure 6. Vulnerability to food insecurity declines with appropriate adaptation**
*Source*: Karfakis *et al.* (2011a).

level options, this research shows that the impact of global warming affecting farmers' consumption through land productivity is substantial.

The results also provide evidence regarding the choice of appropriate policy instruments that would significantly help in reducing household vulnerability. As shown in Figure 6, vulnerability under climate change and without any adaptation is significantly high (there is an average probability of 42 percent for a household to become food insecure in the near future). Universal access to minimum levels of education and improved agricultural practices through the wider application of pesticides and fertilizers are able to reduce some part of this vulnerability. Jointly these adaptation measures reduce the vulnerability probability to 36 percent on average.

## POLICY OPTIONS AND RECOMMENDATIONS

A wide range of policy messages emerge from the assessment of this preliminary evidence and other relevant knowledge sources that discuss the coping and risk management challenges imposed on households by the climate changes and other global trends. Suggested policy measures formulate a comprehensive framework that incorporates the conjoint promotion of what is frequently called **climate-smart agriculture** (Lipper *et al.,* 2010) along with radical progress in **agricultural innovation systems** (World Bank, 2012). This framework involves the close partnership of private and public sectors under a global umbrella of food security governance that tries to accommodate the agenda of challenges at local level along with multilateral solutions.

**Identifying vulnerable populations is not a straightforward task.** Initially and in order to address the effects of climate change, the development community and national policy-makers should not necessarily (or only) restrict their attention to addressing the needs of farmers. Farmers, especially those integrated into markets, in general are expected to benefit from the higher crop prices brought about by the adverse impacts of climate changes on yields as well as from the increased demand for alternative uses of crops (e.g. biofuels). It is not, however, straightforward that the higher revenues along with the higher costs of most inputs will generate sufficient profit margins for farmers to cover their basic or other needs. Moreover, it is not clear how these revenues will be distributed across the diverse spectrum of farmers in developing regions.

**Major attention should be paid to net buyers of food.** If, however, net food producers in temperate or tropical regions eventually benefit from projected trends in climate, demographic changes and other trends, then the vulnerable groups most in need for support are the net buyers of food in urban as well as in rural areas. In that case, mostly semi-skilled or unskilled wage earners in different sectors including agriculture are expected to face severe food insecurity challenges especially in view of the high population pressures – urbanization trends that are already being felt and are expected to increase in the future.[6]

At the micro or livelihood level, adaptation practices to changes in average and variability of the climate in different localities remain the principal policy priority, especially for farmers in rural areas of the developing world. Such policies can be agricultural-specific, which try to increase the efficient use of available resources and products while integrating sustainability features. In this case, improved management of water resources,[7] extension services, efficient use of fertilizers and pesticides (reducing overuse if needed), diversifying the crop mix,[8] sustainable practices in extensification and intensification of arable agricultural land, reducing the wastage of food crops through better management of stocks and household consumption are examples of adaptation practices that should be promoted across the board. In this way, the natural reproductive rate of environmental resources will likely be sufficient to cover the rates of their use, also satisfying the needs of current and especially future generations as the very meaning of sustainability signifies.

Policy measures beyond the agriculture sector are also important. On the other hand, not necessarily agricultural-specific policies are always required to address the nexus of development challenges that rural areas are constantly subject to. Investments in infrastructure, the development of credit markets, diversified income sources, policies to increase the general level of human and physical capital, improvements in access to health services and the management of climate-related or other diseases, access to a wider pool of assets and resources, addressing critical institutional constraints and other standard development prerequisites are able to support both farmers as well as economy-wide challenges in the face of climate trends.

Safety nets for vulnerable groups remain key policy priority. For farmers that are not able to adapt and benefit even when the sector's prospects improve, then safety nets supporting their production and agricultural supply as well as their consumption patterns (if those are severely threatened) are needed, and may entail distribution of food or other consumable goods if necessary. In this case, exit from the agriculture sector can be expected, especially when contemporaneous development efforts in the economy as a whole turn out to be successful. Safety nets are equally important for vulnerable groups not working in agriculture (urban or rural poor) that spend a significant share of their income on food.

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[6] Research indicates a series of channels through which overpopulation and associated changes in the demographic structure (e.g. increasing life expectancy) of the populations may affect welfare and food security. However, the most important ones refer to the fact that population growth dilutes capital per person, while congestion in the use of natural resources and fixed inputs, such as land and the environment, will further challenge food security. Moreover, it is expected that larger population increases and any resulting food insecurity concerns will take place in poorer countries rather than in richer ones. The population of Africa will increase tenfold between 1950 and 2050 while several developed countries already face population growth rates that approach zero. On the other hand, many of the African and other developing countries rely heavily on exhaustible natural resources. Under certain assumptions halving the population of a poor country that earns about 30 percent of their income from exports of minerals or energy would increase per capita incomes by 25 percent. But investments from richer countries directed to poorer ones, among which the income differences are more than twentyfold, would have much more positive and sustainable benefits.

[7] Kurukulasuriya *et al.* (2006), using survey data from several sub-Saharan countries, show that in areas where irrigation systems are already applied increased temperatures may be able to generate increases in crop yields.

[8] Niggol Seo (2010) estimates that land values in Latin America may fall by only 10 percent in the case of a mixed crop system relative to a –20 percent decline in the case of farms that specialize in the production of a small number or a single crop.

Exit from the agriculture sector should be a crucial policy concern. The reductions in the relative importance of agriculture in national GDPs, as well as the reduction of the agricultural labour shares, remain uniformly observed empirical regularities along the development transition paths of the economies so far. If this remains the case in the face of future climate and other trends that may improve (but not enormously) the prospects for agriculture, then policies to facilitate the exit from the sector and the entry into the manufacturing and the services sectors should be set in place (e.g. policies that facilitate labour mobility and investments in other sectors).

Technical innovations (research and development) in agriculture are required. Finally, from a policy point of view that goes beyond the household level, it always remains necessary to innovate by investing in research and development towards technologies that will modify the properties of crops, increasing their heat tolerance and drought resistance, as well as the properties of land in order to cope with declining yields and overconsumption of nutrients, in different agro-economic zones. At a similar level, other types of policies regarding the mitigation of climate change remain highly relevant in trying to reduce the sources of greenhouse gases or increase their sinks.

Lifting organizational constraints in agricultural markets can increase food efficiency savings. It has to be noted that innovations in agricultural systems are required – but not only in order to address technical issues and constraints. They should also resolve organizational bottlenecks starting at the production level, through the marketing of crops and greater distribution channels until final consumption so that efficiency gains are maximized (e.g. minimize storage times, efficient transportation channels and wastage across the value chains). In addition, information acquisition and dissemination solutions are important factors that contribute not only to exploiting profit opportunities but also to facilitating adoption of technologies, especially new ones that enhance greener features. Innovation systems are a cross-cutting issue that applies both at macro and micro levels.

## CONCLUDING REMARKS.

The present paper provides a review of the existing evidence regarding the impacts of climate change on household level welfare as measured either by changes in poverty, in food security, in the value of farm assets (e.g. land), in income, consumption or health outcomes. From this review, the impacts, even though they vary, are usually expected to undermine further the welfare position of poorer farmers and net buyers of food both in rural and urban areas.

The paper further suggests how analytical methods (vulnerability and resilience analysis) that are being tested in FAO can assist in filling part of the knowledge gap existing in the study of these impacts. Given the ability of the methods to model the channels through which climate changes are transmitted to households and affect their welfare, adaptation weaknesses can be identified with relative confidence and validate policy support in building household resilience.

It is a key message of the present work that building knowledge on the expected impacts of climate change at the household level has to be systematically promoted. An FAO pilot study on vulnerability to food insecurity from climate changes in Nicaragua (Karfakis *et* *al.*, 2011a) assists in describing analytically a relatively comprehensive chain of logical events regarding the impacts of climate change for farm households. A multilevel approach including this type of analysis is implemented by the Climate Energy and Tenure (NRC) and Agricultural Development Economics (ESA) Divisions of FAO, in the context of a project funded by the Ministry of Agriculture, Fisheries and Forestry (MAFF) of Japan, in the Philippines and another country of the Asian Pacific Economic Cooperation (APEC).[9] A relevant project led by ESA Division, co-funded by the European Commission (EC) and FAO, is also trying to address climate change constraints on household food security and promote climate-smart adaptation practices in Malawi, Zambia and Viet Nam.[10] The principal objective of both projects is to integrate climate change-relevant policies effectively into agriculture sector strategies.

All preliminary evidence suggests that adaptation-enhancing practices will be the most important policy option in smoothing the food security and poverty impacts of climate change of affected households including farmers. Such options include both practices that have to promote a more efficient use of available resources and inputs (i.e. climate-smart agriculture practices) along with the promotion of developmental objectives (e.g. universal basic education).

Nevertheless, the obligations for governments and the international development community, in partnership with the private sector, to adopt macro-level coping strategies should not be neglected. These top-down responses are absolutely necessary to enhance the capacity to confront the challenges that result from climate change, demographic trends and the exhaustive use of natural resources, and manage with what currently looks like the end of agricultural productivity growth that may be approaching.

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[9] The project is entitled "Assessments of Climate Change Impacts and Mapping of Vulnerability to Food Insecurity under Climate Change to Strengthen Household Food Security with Livelihoods' Adaptation Approaches (AMICAF)".

[10] The project is entitled "Climate Smart Agriculture: Capturing the Synergies between Mitigation, Adaptation and Food Security".

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# The urgency to support resilient livelihoods: FAO Disaster Risk Reduction for Food and Nutrition Security Framework Programme

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## DISASTER RISK REDUCTION IN THE CONTEXT OF CLIMATE CHANGE AND FOOD INSECURITY

The multiple threats to food and nutrition security, their negative and cumulative impact, and the clear **links between shocks and hunger** reveal the fragility of current food production systems (and also of sustainable development) and their vulnerability to disasters, crises and conflicts. The Special Report on Managing the Risks of Extreme Events and Disasters to advance climate change adaptation (SREX) stresses the interaction of climatic, environmental and human factors leading to impact and disaster. The character and severity of impacts and of risks depend on the shock (or extremes) themselves but also on the exposure (presence of people; livelihoods, environmental services and resources; infrastructure; or economic, social or cultural assets in places that could be adversely affected) and vulnerability (the propensity or predisposition to be adversely affected) (IPCC, 2012).

**Disasters** have adversely affected the lives and livelihoods of millions over the past years with particular deleterious consequences for the poor and politically marginalized. The impacts of the catastrophic earthquake in Haiti in January 2010 and floods in Pakistan in July 2010 show how disaster risk and poverty are closely interlinked. The 2011 Horn of Africa drought crisis also stresses the interconnection between natural disaster and conflict situations, magnifying the impact of the drought. Meanwhile, in 2011, floods in Australia, the earthquake in Christchurch, New Zealand, and the earthquake, tsunami and nuclear disaster wreaking havoc in northeastern Japan are a stark reminder that developed countries are also very exposed. Less visible internationally, hundreds of smaller disasters associated with climate variability have caused enormous damage in Benin, Brazil, Colombia, the Philippines, Indonesia and other countries. These events reveal how risks are continuously constructed through existing development gaps and growth in economic and population exposure. Moreover, as the Japan disaster highlighted, there are emerging risks and new vulnerabilities associated with the complexity and interdependency of the technological and ecological systems on which modern societies depend. Large-scale or mega-disasters with interactions between physical and technological hazards and the exposure of countries to a wide range of emerging risks and new patterns of vulnerability can trigger cascading and concatenated system breakdowns at different scales, which are difficult to model or to prepare for, but which can exponentially magnify negative impacts and affect multiple countries or regions or even the planet (UNISDR, 2011).[1]

The vast **majority of damage, losses and impacts** are extensive in character, occurring throughout a country's territory. A rising number of localized disasters are responsible for significant impact on human and natural resources such as housing, crops, livestock and local infrastructure, and particularly affect low-income households and communities.[2] The past 20 years have seen an exponential increase in the number of local areas reporting losses (Figure 1). Increasing extensive risks are closely related to the challenges low- and medium-income countries face in addressing underlying risk drivers and reducing vulnerability. Most governments have yet to find effective ways of reducing and managing natural and human-induced disaster risks.

Assumptions about disasters are being increasingly challenged, as new drivers of risk emerge and interact. A number of potential and plausible risks are difficult to identify or have profound potential consequences, so it is difficult to find an entry point for risk modelling and analysis[3]. There may be no precedent for the emerging risks associated with low probability hazards as research reveals the increasingly complex vulnerabilities related to the growing interconnection and interdependency of societies. The risks associated with increased incidence and spread to new geographic areas of transboundary plant pest and animal diseases also loom ahead.[4] As such, there is a growing probability of 'simultaneous crisis' where different hazards/shocks occur at the same time, 'sequential crisis' where hazards trigger cascading disasters in a range of interlocked systems and 'synchronous failures' (i.e. the March 2011 Japan earthquake-tsunami-nuclear crisis) where different risks converge and interact.

As with disaster and crisis risk management in general, the additional challenge of **adapting to climate extremes/change** requires increased attention to underlying conflict and disaster risk drivers, reducing vulnerability and strengthening risk governance capacities. If disaster risks can be reduced, then the magnifying effect of climate change will also be reduced and adaptation will be facilitated. Disaster risks and climate change threaten food and nutrition security (FNS) and actions on both fronts are needed to protect and build the resilience of livelihoods. As indicated in Figure 2, both disaster risk reduction (DRR) and climate change adaptation are concerned with the increase in the number and

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[1] This second edition of the United Nations Global Assessment Report on Disaster Risk Reduction provides a current resource for understanding and analysing global disaster risk. Drawing on a large volume of new and enhanced data, it explores trends and patterns in disaster risk globally, regionally and nationally. In parallel, more than 130 governments are engaged in self-assessments of their progress in implementing the Hyogo Framework for Action (HFA), contributing to what is now the most complete global overview of national efforts to reduce disaster risk.

[2] FAO in its "save and grow" policy guidance indicates that about 2.5 billion smallholders are particularly at risk with vulnerable livelihoods.

[3] Between 1601 and 1603 Russia suffered the worst famine in the country's history. It is estimated that over two million people starved to death in Russia as a whole. It was only recently, however, that climate researchers established a conclusive link between the failure of harvests in Russia in 1601 and the ash cloud produced by the catastrophic explosion of the Huaynaputina Volcano in southern Peru on 19 February 1600.

[4] As seen with the bird flu-HVAI and H1N1 pandemics.

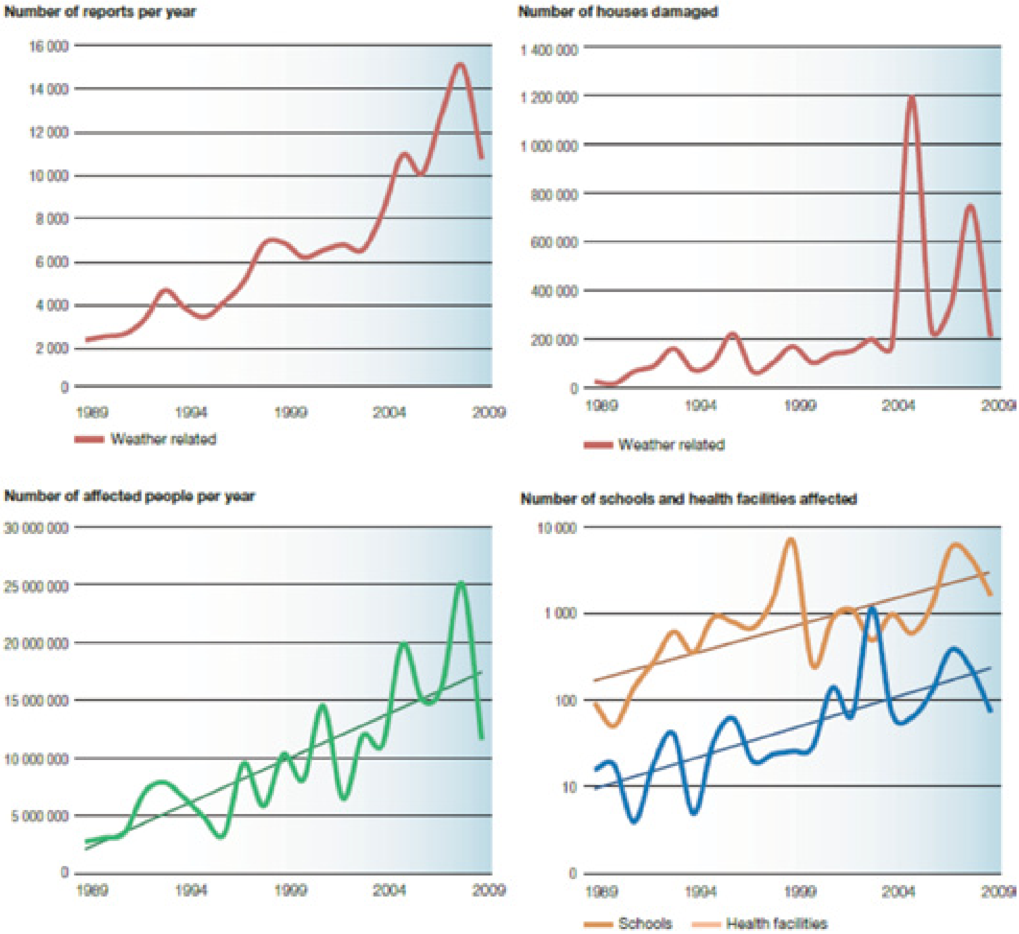

**Figure 1. Extensive risk trends by indicator (for the 21 countries and states included in the GAR11 analysis)**

scale of extreme climate-related hazards, and the changing patterns of risk and vulnerability expected from climate change. As the world is expected to experience climate-related hazards on an unprecedented scale, it is necessary to scale-up and accelerate efforts in both DRR and climate change adaptation, with the shared policy objective of supporting sustainable development and the achievement of the Millennium Development Goals. Decades of DRR experience and research, and the methods and tools developed and practised, can be used to guide adaptation planning and to help countries better manage the expected change in the frequency and intensity of severe weather patterns.

Short-, medium- and long-term humanitarian and development policies/strategies/programmes and actions must urgently be redefined to take into account and reduce the various and interconnected risks to reach millions of risk-prone citizens.

Countries with **weak governance, political instability or in conflict** (complex emergencies or protracted crisis) are likely to find it difficult to address underlying conflict and

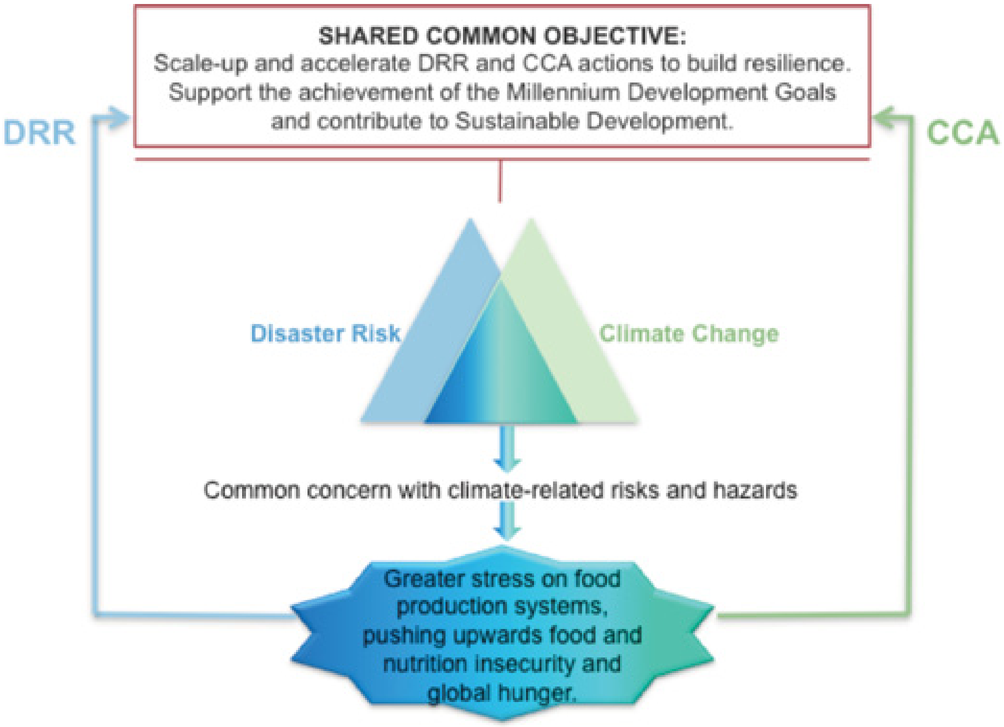

**Figure 2. Disaster risk reduction and climate change adaptation**
*Source*: FAO (2011).

disaster risk drivers (i.e. degradation of hazard-regulating ecosystems such as wetlands, mangroves and forests, high levels of poverty and political/economic marginalization, badly managed urban and regional development, etc.). Extreme hazards and events are not synonymous with extreme risks. When similar numbers of people are affected by hazards of similar severity, wealthier and poorer countries generally experience radically different losses and impacts. **Poverty is both a cause and consequence of disaster risk** (UNISDR, 2009). Across all the major hazards, poorer countries with weaker governance[5] tend to experience higher mortality and greater relative economic loss compared with wealthier countries with stronger governance. Mortality risk, for example, is approximately 225 times greater in low-income countries compared to OECD countries, when similar numbers of people are exposed to tropical cyclones of the same severity (UNISDR, 2011). Whereas relative wealth is a key determinant, governance factors, such as the strength of democracy and voice and accountability, all play roles in the social construction of risk. The quality of a country's governance appears to have a significant influence on the underlying drivers of risk. Risk drivers and increasing poverty and inequality interact through multiple feedback loops and together translate hazards into disaster risk. Mortality is still rising in the countries with the weakest risk governance capacities, affecting particularly women and children.

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[5] Governance refers to the actions, processes, traditions and institutions by which authority is exercised and decisions are taken and implemented.

**The alleviation of hunger and poverty** is strongly correlated with DRR. Millennium Development Goal 1 (Target 1C) strives to eradicate extreme poverty and hunger, and aims to halve by 2015 the proportion of people who suffer from hunger. The World Food Summit goal is to reduce, by 2015, the number of undernourished people by half. Yet these targets are compromised by natural disasters, protracted crises and armed conflicts that reverse development and poverty-reduction gains, destroy livelihoods, reduce food production and increase hunger. Worldwide, there are 925 million undernourished people, and hungry people account for 16 percent of developing countries' populations (FAO, 2010). Future investment must be guided by the principles of sustainable development while also promoting prosperity and peace.

## HAZARDS, THREATS AND CRISES AFFECTING FOOD AND NUTRITION SECURITY

**Floods, hurricanes, tsunamis and other hazards** destroy agricultural infrastructure and assets, crops, inputs and production capacity. Drought alone has caused more deaths during the last century than any other physical hazard. Asia and Africa rank first among continents in the number of people directly affected, while Africa has a high concentration of deaths associated with drought (UNISDR, 2011). These natural hazards have a direct impact on agriculture and food security. They interrupt market access, trade and food supply to the cities. They reduce income, deplete savings and erode livelihoods. They also have a negative consequence for animal production by reducing range productivity and rangeland yields, leading to food insecurity, overgrazing and degradation of ecosystems. Livestock is central to the livelihoods of the poor. It forms an integral part of mixed farming systems. It is an important source of employment, income, quality food, fuel, draught power and fertilizer. Fisheries and aquaculture, a sector that is a critical contributor to food supply, income generation and food security, also suffers tangible losses as a result of natural disasters, including damage to fishing infrastructure and productive assets such as docks, landing and processing facilities, boats and fishing gear. In addition, diseases threaten fish and contribute to food and nutrition insecurity among rural populations dependent on fish farming. Over 500 million people depend, directly or indirectly, on fisheries and aquaculture for their livelihoods. Fish also provide essential nutrition to three billion people, including at least 50 percent of the animal protein and essential mineral intake of 400 million people in the poorest countries. New transboundary aquatic animal diseases continue to appear, causing losses in aquaculture and capture fisheries and adversely affecting local economies. For example, in 2009, fish stocks in the Zambezi River Valley were infected by epizootic ulcerative syndrome, threatening to spread the disease to seven countries surrounding the river basin and potentially affecting the food security and livelihoods of 32 million people.

**Transboundary plant pests and diseases**, such as locusts, armyworms and wheat rust, and transboundary animal diseases such as African swine fever, foot-and-mouth disease and Rift Valley fever, have a direct economic impact by reducing or eliminating agricultural and livestock production. Furthermore, pests and diseases may adversely affect prices and trade, negatively affecting farm income. Reduced productivity of crops or animals can have a long-lasting effect as well. Pest infestations can impair fertilization rates or seed recovery.

Diseases can have lasting effects on livestock output by delaying reproduction, leading to a reduced population and extended food and nutrition insecurity.

**Wildfires in forests and other natural resources** also affect rural livelihoods. An estimated 150 to 250 million hectares of tropical forests are affected by wildfire annually. Close to 1.6 billion people – more than 25 percent of the world's population – rely on forest resources for their livelihoods and most of them (1.2 billion) use trees on farms to generate food and cash. Moreover, many countries in the developing world draw on fuelwood to meet as much as 90 percent of energy requirements and this creates additional energy risks.

**The natural resources degradation or environmental factor:** as highlighted by the United Nations International Strategy for Disaster Reduction, "the environment and disasters are inherently linked" because of the strong dependency and interconnectedness of natural resources with the environment (UNISDR, 2004). Deforestation, degradation of catchments/watersheds, degradation of land and desertification, depletion of reefs and coastal ecosystems especially of corals and mangroves, among other factors, reduce nature's defense capacity against hazards and aggravate the impact of disasters such as floods, landslides, storm surges, hurricanes and drought. Disasters in turn contribute to ecosystem degradation and loss, including increased soil erosion, declining rangeland quality, salinization of soils and biodiversity loss. Increasing environmental degradation reduces the availability of goods and services to local communities, shrinks economic opportunities and livelihood options, and ultimately contributes to greater food insecurity and hunger. It further drives increasing numbers of people to marginal lands and fragile environments. To reduce risks, it is vital to build the resilience of the natural resource base, and to promote sound environmental and natural resource management practices and the sustainable use of ecosystems. Healthy and diverse ecosystems are more resilient to hazards. Forests are estimated to save between USD 2–3.5 billion per year equivalent in disaster damage restoration of key forest ecosystems (Sudmeier-Rieux and Ash, 2009). They can be used as shelterbelts and windbreaks, and also play an important role in protecting against landslides, floods and avalanches. Trees stabilize riverbanks and mitigate soil erosion, while woodlots provide fuelwood, timber and fodder. Wetlands serve to store water, provide storm protection, flood mitigation, shoreline stabilization and erosion control. Barrier reefs, barrier islands and mangroves can help mitigate hurricane risk, storms and tidal surges. Getting the right energy source and technology can play a significant role in managing the environment in support of risk reduction, such as in the productive use of land (e.g. liquid fertilizer from biogas) and/or by reducing deforestation through the use of improved or non-wood-dependent cooking stoves.

**Water scarcity,** projected to increase worldwide even without climate change, is also intricately linked to disaster risks and food insecurity. The exploitation of subterranean water reserves, for example, is contributing to desertification in many parts of the world; as subterranean water levels recede, the soil near the surface dries out and plants wither and die. With continued deforestation and exploitation of subterranean water reserves it is likely that many more parts of the world will face severe water shortages. Agriculture accounts for more than 70 percent of the world's total water use. Irrigation is a direct source of livelihood for hundreds of millions of the rural poor in developing countries. As farmers face the challenge of accessing an increasingly scarce resource, groundwater levels continue falling each year, causing more rivers to dry up. In arid and semi-arid regions water scarcity is almost endemic, placing greater pressure on both surface and groundwater resources to meet domestic and irrigation demands. Drought is another major cause of water shortage with devastating impacts, especially in countries with reduced capacity to absorb the shocks. Prolonged or frequent drought episodes can lead to the irreversible stage of desertification unless adequate measures are taken to increase the resilience of countries prone to such phenomena. DRR efforts need to support enhanced management and conservation of water resources. This includes improved capture and utilization of rainfall, such as rainwater harvesting, and the adoption of water conservation technologies and practices that use less water and reduce water loss, such as using drip and furrow irrigation to increase water productivity.

Inadequate **land-use planning and tenure** contribute to increasing the vulnerability of communities exposed to hazards. Land zoning and land-use management, including regional and territorial planning, need to consider the spatial parameters of physical vulnerability based on hazard and risk mapping. Better land access and secure tenure enable food production and provide an incentive for landholders to invest in improving their land with soil protection measures, tree planting, improved pastures, water conservation technologies or sustainable crop production.

The effective management of land, water systems, forests, wetlands, soils, and other resources is necessary for redressing the root causes and environmental drivers of vulnerability and risks, especially for food and nutrition security.

The incidence of **food crises**, which are caused by severe adverse weather conditions, natural hazards, economic shocks, conflicts, or a combination of these factors, has been rising since the early 1980s. There have been between 50 and 65 food emergencies every year since 2000, up from 25 to 45 during the 1990s (FAO, 2008).

**Economic crises** constitute yet another threat that impacts on poverty and hunger. The past two years have witnessed a rapid increase in the number of hungry, largely influenced by the global food and fuel crisis. A similar pattern was observed between 2003 and 2005 and in 2007–2008, with high food prices followed by a rapid increase in chronic hunger. In 2008, 75 million people were added to the total number of undernourished relative to 2003–2005 (FAO, 2008)· World food prices surged to a new historic peak in February 2011 and these high prices are expected to persist in the future. These crises create poverty traps and increase the prevalence of food insecurity and malnutrition by reducing real income and forcing the poor to sell their valuable assets, decrease their food consumption and reduce their dietary diversity. The impact is strongly felt in low-income, food-deficit countries that may face problems in financing food imports, and for poor households that spend a large share of their income on food. The urban poor are particularly affected by soaring food prices. They do not produce food but rather invest the bulk of their income on food expenditures and have no alternative access to food other than local markets.

Countries in **protracted crisis** situations, which are characterized by recurrent natural disasters and/or conflict, longevity of food crises, breakdown of livelihoods and insufficient institutional capacity to react to the crises, show high levels of food insecurity. On average, the proportion of people who are undernourished is almost three times as high in countries in protracted crisis as in other developing countries (FAO, 2008). The level of undernourishment in this set represents 166 million people, roughly 20 percent of the world's undernourished people (or more than a third of the global total if China and India are excluded). In countries in protracted crises, the Millennium Development Goal 1 and the World Food Summit goal are very unlikely to be met by 2015. These poor food security outcomes are long-lasting and are closely related to recurrent natural disasters and/or conflict, the number of years in crisis, the breakdown of livelihoods, weak governance or public administration and, most importantly, the overall insufficient capacity to react to the crises (in some of these countries crises are localized to only certain areas or regions).[6] Development and investments that generate or exacerbate inequalities or deepen exclusion can increase the risks of conflicts.

Food and agriculture sectoral strategic guidance is needed to help countries to comply with the Hyogo Framework for Action (HFA) and to reduce and manage multihazards and various risks magnifying vulnerabilities to food and nutrition insecurity (especially for the poorest). At global, regional, national and local levels, coherent interventions and systems are needed to build, prevent, protect and restore resilient livelihoods of farmers, herders, fishers, foresters and other vulnerable groups (estimated to be more than 2.5 billion smallholders according to FAO "Save and Grow") against various threats and shocks. Crisis and disaster risk reduction and management for food and nutrition security are vital for ensuring one of the most basic human rights – "the right to food and freedom from hunger". At all levels, correlated or nested governance, information and early warning, preparedness and crisis response systems and mechanisms for DRR for agriculture and food and nutrition security related sectors should be urgently developed to face the hunger and poverty challenges ahead.

## THE FAO FRAMEWORK PROGRAMME: DISASTER RISK REDUCTION FOR FOOD AND NUTRITION SECURITY

**Providing DDR for food and nutrition security related sectors or the urgency to support resilient livelihoods of vulnerable smallholders:** In line with the above findings, sectoral DRR is urgently needed. DRR for food and nutrition security is a crucial gap. Therefore, FAO recently developed and released its new Framework Programme on Disaster Risk Reduction for Food and Nutrition Security. This interdisciplinary framework provides strategic direction to FAO member countries and partners for the implementation of DRR measures in agriculture, livestock, forestry, fisheries, aquaculture and natural resources management at local, national, regional and global levels. The document

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[6] Extracted from *Addressing food crises - towards the elaboration of an agenda for action in food security in countries in protracted crisis*, High-Level Expert Forum (HLEF), Introduction – setting the context of 36th CFS recommendations on further analysis and actions on food security in protracted crisis. (FAO, 2010).

is online and available for direct download[7] at http://www.fao.org/fileadmin/templates/tc/tce/pdf/FAO_Disaster_Risk_Reduction.pdf

The summary of the FAO corporate strategic framework programme of DRR for FNS is as follows:

Through its disaster risk reduction activities, the Food and Agriculture Organization of the United Nations (FAO) seeks to protect livelihoods from shocks, to make food production systems more resilient and more capable of absorbing the impact of, and recovering from, disruptive events.

Disaster risk reduction protects development investments in the agriculture, livestock, fisheries/aquaculture and forestry sectors, helping the world's most vulnerable people become food secure. Disaster risk reduction is vital for ensuring one of the most basic human rights – the right to food and freedom from hunger. Furthermore, disaster risk reduction creates a multiplier effect that accelerates the achievement of Millennium Development Goal 1: the eradication of extreme poverty and hunger.

At FAO, disaster risk management is a corporate priority. It is expressed in FAO's Strategic Framework 2010–19 through Strategic Objective I: Improved preparedness for, and effective response to, food and agricultural threats and emergencies. As an integral part of this objective, FAO makes a specific commitment to disaster risk reduction: "countries' vulnerability to crisis, threats and emergencies is reduced through better preparedness and integration of risk prevention and mitigation into policies, programmes and interventions".

The FAO Disaster Risk Reduction for Food and Nutrition Security Framework Programme serves to support and provide strategic direction, to FAO member countries and partners, for the implementation of Disaster Risk Reduction for Food and Nutrition Security programmes.

This Framework Programme reflects the Hyogo Framework for Action and strives to assist member countries implement its five Priorities for Action for the agricultural sectors. It also responds to recent recommendations made on disaster risk reduction by the Committee on Agriculture, the Programme and Finance Committee, the Committee on World Food Security and the Committee on Fisheries. It contributes to meeting the needs of member countries, as expressed in the Regional Areas of Priority Action and identified by FAO Regional Conferences held in 2010.

The goal of the FAO Disaster Risk Reduction for Food and Nutrition Security Framework programme is to enhance the resilience of livelihoods against threats and emergencies to ensure the food and nutrition security of vulnerable farmers, fishers, herders, foresters and other at risk groups.

While the Framework Programme supports national government partners, the direct beneficiaries are smallholders in developing countries, including small-scale farmers, fishers, herders, foresters and the urban poor – particularly women – whose lives and livelihoods are threatened. Small-scale farmers represent 90 percent of the rural poor and make up the majority of the world's hungry population.

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[7] FAO has also developed a framework programme called "FAO Adapt" in relation to its climate change adaptation for food and nutrition security. The "Climate-Smart Agriculture" concept is also relevant as well as its "Save and Grow" strategy. All these are also relevant for resilient communities and resilient food systems.

At the core of the Disaster Risk Reduction for Food and Nutrition Security Framework Programme are four integrated and complementary thematic pillars:

### PILLAR 1 – ENABLE THE ENVIRONMENT

**Institutional strengthening and good governance for DRR in agricultural sectors.**
Pillar 1 seeks to support the enabling environment of member countries, with appropriate legislation, policies and institutional frameworks for disaster risk reduction for food and nutrition security in agriculture, livestock, fisheries/aquaculture, forestry and natural resource management, and to strengthen the institutional capacities to implement these.

### PILLAR 2 – WATCH TO SAFEGUARD

**Information and early warning systems on food and nutrition security and transboundary threats.**
Pillar 2 seeks to strengthen and harmonize food and nutrition security information and early warning systems to better monitor the multiple threats and inform decision-making in preparedness, response, policy, advocacy and programming.

### PILLAR 3 – PREPARE TO RESPOND

**Preparedness for effective response and recovery in agriculture, livestock, fisheries and forestry.**
Pillar 3 seeks to strengthen capacities at all levels in preparedness to improve response to, and recovery from, future threats to food and nutrition security, and to reduce their potential negative impact on livelihoods.

### PILLAR 4 – BUILD RESILIENCE

**Prevention, mitigation and building resilience with technologies, approaches and practices across all agricultural sectors.**
Pillar 4 seeks to address the underlying risks to food and nutrition security and build the resilience of livelihoods through the application of technologies, practices and approaches in farming, fisheries/aquaculture, forestry and natural resource management.

Together, the four pillars address core themes in DRR for FNS. Each pillar directly contributes to one of the Priorities for Action in the Hyogo Framework for Action. The pillars include options for capacity development that indicate, by way of example, a range of technical services, technologies, good practices that FAO can provide, and from which member countries can select based on their needs and priorities.

The four pillars address DRR as a whole. They are interdependent and mutually reinforcing. The Framework Programme promotes the integrated implementation of the four pillars for a more holistic approach, striving to maximize the synergies and complementarities between the pillars and hence the critical links between good governance, early warning, preparedness, mitigation and prevention.

The four cross-cutting priorities of the Framework Programme are in line with the core functions of FAO's Strategic Framework. They include:

1) capacity development
2) knowledge management and communication
3) strategic partnerships
4) gender equity

The Framework Programme gives strategic direction and guides the implementation of DRR measures for FNS in member countries. FAO has been implementing disaster risk reduction activities within the context of its Strategic Framework and Programme of Work and Budget, including the development of regional programmes on disaster risk reduction and disaster risk management. Building on existing DRR interventions, the Framework Programme consolidates FAO's cross-sectoral expertise on DRR under one umbrella. It is a coherent corporate commitment for scaling-up actions for disaster risk reduction for FNS at local, country, regional and global levels.

## RECOMMENDATIONS

On the way forward, FAO recommends the following set of five actions:

- provide increasing importance and substantial investment in the key four pillars of the DRR for FNS as an entry point for climate change adaptation;
- generate and maintain an enabling policy and institutional environment for improving DRR for FNS to reduce vulnerability and exposure to disasters risks of livelihoods and ecosystems on which they depend;
- continue improvements and investments in early warning, risk analysis and food security and nutrition surveillance, accountably linked to mechanisms for mitigating, preparing for and responding to food and nutrition crises;
- support and increase timely resource allocation to crisis prevention and preparedness capacities for communities, civil society institutions, private sector, governments, regional and international bodies;
- promote research, innovation and measures to enhance resilience of individuals, communities and ecosystems in the face of known and emerging risk patterns.

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# Agriculture in National Adaptation Programmes of Action

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## INTRODUCTION

As pointed out by the World Bank (2008), agriculture continues to be a fundamental instrument for sustainable development and poverty reduction. It contributes to development in many ways. The World Bank (2008) defines agriculture-based countries as those countries to which agriculture's aggregate contribution to growth over the past 20 years exceeds 20 percent *and* where most of the poor are in rural areas, using the USD2-a-day poverty line (on average 70 percent). In agriculture-based countries, agriculture generated an average 29 percent of the gross domestic product (GDP) in 2005, with 65 percent of the workforce. Importantly, in such countries, annual agricultural GDP growth out-weighted the non-agricultural GDP growth by 0.5 point, and such GDP growth benefitted the poorest half of the population substantially more. Currently, 2.5 billion people live in households that are involved in agriculture. In transforming and urbanized countries, agriculture plays an important indirect role in the economy as industries and services linked to agriculture often account for more than 30 percent of the GDP.

Climate change adds a new challenge for agricultural and rural development (Füssel, 2009; Hassan, 2010; Nzuma *et al.,* 2010; Padgham, 2009; World Bank, 2009). The poorest countries, and especially the least developed countries (LDCs), are often among the most impacted by the adverse physical impacts of climate change, and even more in economic terms, because of the importance of the agricultural sectors in their economy and in terms of employment. At the same time they have less adaptive capacity.

Recognizing these specificities, the United Nations Framework Convention on Climate Change (UNFCCC) has established National Adaptation Programmes of Action (NAPAs) as a dedicated, harmonized, but country-led process for LDCs to identify their priority activities that respond to their urgent and immediate needs to adapt to climate change.

To date, 47 NAPAs have been prepared. They include 490 priority projects, constituting a valuable picture of the landscape of high priority projects as defined by the most vulnerable countries reflecting their urgent needs in the face of climate change vulnerability today. As such, they can also give an idea of future needs in less vulnerable countries.

The aim of this summary survey of agriculture in the NAPAs is to determine the importance of agriculture (in the FAO acceptation as "agriculture, forestry and fisheries") and provide a first analysis of priority measures in NAPAs in order to highlight priority topics and areas.

# 1. THE NATIONAL ADAPTATION PROGRAMMES OF ACTION)

## 1.1 The least developed countries

The category of LDCs was officially established in 1971 by the UN General Assembly with a view to attracting special international support for the most vulnerable and disadvantaged states. The current list of LDCs includes 48 countries – 33 in Africa, 14 in Asia and the Pacific and 1 in Latin America.

The LDCs comprise more than 880 million people (about 12 percent of world population), but account for less than 2 percent of world GDP and about 1 percent of global trade in goods. They often cumulate various factors of vulnerability. Their low level of socio-economic development is characterized by weak human and institutional capacities, low and unequally distributed income and scarcity of domestic financial resources. They often suffer from governance crisis, political instability and, in some cases, internal and external conflicts.

**Box 1: The definition of least developed countries**

The identification of least developed countries (LDCs) is currently based on three criteria: per capita gross national income (GNI), human assets and economic vulnerability to external shocks. The latter two are measured by two indices of structural impediments, namely the human assets index and the economic vulnerability index.

1. Low-income criterion, based on a three-year average estimate of GNI per capita, based on the World Bank Atlas method (under USD992 for inclusion, above USD1 190 for graduation as applied in the 2012 triennial review).
2. Human Assets Index (HAI) based on indicators of: (a) nutrition: percentage of population undernourished; (b) health: mortality rate for children aged five years or under; (c) education: the gross secondary school enrolment ratio; and (d) adult literacy rate.
3. Economic Vulnerability Index (EVI) based on indicators of: (a) population size; (b) remoteness; (c) merchandise export concentration; (d) share of agriculture, forestry and fisheries in GDP; (e) share of population living in low elevated coastal zones; (f) instability of exports of goods and services; (g) victims of natural disasters; and (h) instability of agricultural production.

To be included in the list of LDCs, a country must satisfy all three criteria. In addition, because the fundamental meaning of the LDC category, i.e. the recognition of structural handicaps, excludes large economies, the population must not exceed 75 million.

To become eligible for graduation out of the list, a country must reach threshold levels for graduation for at least two of the aforementioned three criteria, or its GNI per capita must exceed at least twice the threshold level, and the likelihood that the level of GNI per capita is sustainable must be deemed high. To be recommended for graduation, a country must be found eligible at two successive triennial reviews by the CDP.

*Source*: United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and the Small Island Developing States (UN-OHRLLS) http://www.unohrlls.org/en/about/.

Agriculture represents an important part of the economy, often more than 30 percent of GDP, and employs the majority of the population, often more than 75 percent. It provides an important part of fiscal earnings and often contributes significantly to exports (cash crops). At the same time, they are often importers of staple crops. This makes them highly vulnerable to external terms-of-trade shocks and, also, in the case of cash crops, to climatic shocks. Insufficient domestic resource mobilization, chronic external deficits, high debt burdens and heavy dependence on external financing make them particularly vulnerable to shocks. They are, for example, particularly impacted by price volatility (HLPE, 2011).

## 1.2 Development of the NAPAs

Article 4.9 of the UNFCCC recognizes the specific needs and special situations of the LDCs: "*The Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology.*"

In Marrakech in 2001, the 7th Conference of the Parties (COP) also acknowledged the specific situations of LDCs, in that they do not have the means to deal with problems associated with adaptation to climate change, and established an LDC work programme (Decision 5/CP.7) including NAPAs as well as other supporting activities. It was completed by Decision 28/CP.7, which set the guidelines for NAPAs, and by Decision 29/CP.7, which set up an LDC Expert Group (LEG) to provide guidance and advice on the preparation and implementation strategy for NAPAs.

"*The rationale for developing NAPAs rests on the low adaptive capacity of LDCs, which renders them in need of immediate and urgent support to start adapting to current and projected adverse effects of climate change. Activities proposed through NAPAs would be those whose further delay could increase vulnerability, or lead to increased costs at a later stage.*" (Decision 28/CP.7)

The NAPAs focus on urgent and immediate needs – those for which further delay could increase vulnerability or lead to increased costs at a later stage. They use existing information; no new research is needed. They are action-oriented, country-driven, flexible and based on national circumstances. In order to address urgent and immediate adaptation needs effectively, NAPA documents should be presented in a simple format, easily understandable both by policy-level decision-makers and by the public.

The steps for the preparation of the NAPAs include synthesis of available information, participatory assessment of vulnerability to current climate variability and extreme events and of areas where risks would increase owing to climate change and identification of key adaptation measures. It then includes selecting country-driven criteria for prioritizing activities using those provided (see Box 2) and then, using these criteria, a selection of a prioritized short list of activities.

The NAPAs also include short profiles of activities and related projects intended to address urgent and immediate adaptation needs of the country[1].

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[1] For more information see UNFCCC (2009a, b; 2011).

**Box 2: Criteria for selecting priority activities**

A set of locally-driven criteria will be used to select priority adaptation activities. These criteria should include, *inter alia*:

(a) level or degree of adverse effects of climate change;
(b) poverty reduction to enhance adaptive capacity;
(c) synergy with other multilateral environmental agreements;
(d) cost-effectiveness.

These criteria for prioritization will be applied *inter alia* to (this second list is considered as further detailing the first one):

(a) loss of life and livelihood;
(b) human health;
(c) food security and agriculture;
(d) water availability, quality and accessibility;
(e) essential infrastructure;
(f) cultural heritage;
(g) biological diversity;
(h) land-use management and forestry;
(i) other environmental amenities;
(j) coastal zones, and associated loss of land.

*Source*: Decision 28/CP.7.

## 2. AGRICULTURE, SEEMINGLY HIDDEN, IS IN FACT THE DOMINANT SECTOR WITHIN NAPAS' PRIORITY MEASURES

The 47 NAPAs[2] prepared by the LDCs provide a rich panorama of adaptation priority measures. These 490 projects are of special interest and relevance because they have been designed and prioritized by the countries themselves, in an harmonized procedure, which starts by the analysis of potential effects of climate change on each sector, and related vulnerabilities. Key adaptation needs are then derived, *inter alia,* through multistakeholder consultations, and a list of adaptation activities and projects is developed (UNFCCC, 2002). Criteria to rank priority areas included the identification of the most urgent needs, taking into account the vulnerability of sectors, vulnerability of groups, the contribution to food security and to poverty reduction, and economic cost. Such criteria, and the way they have been used, made food security, agriculture and natural resources management issues particularly prominent within the NAPAs. This is an honest mirroring of the fact that LDCs are very dependent on agriculture and natural resources for poverty reduction and food security, both through food production for direct consumption and as a means to provide incomes for the majority of the population, and that these are also the main challenges that are going to be even more difficult to overcome due to climate change.

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[2] http://unfccc.int/cooperation_support/least_developed_countries_portal/submitted_napas/items/4585.php

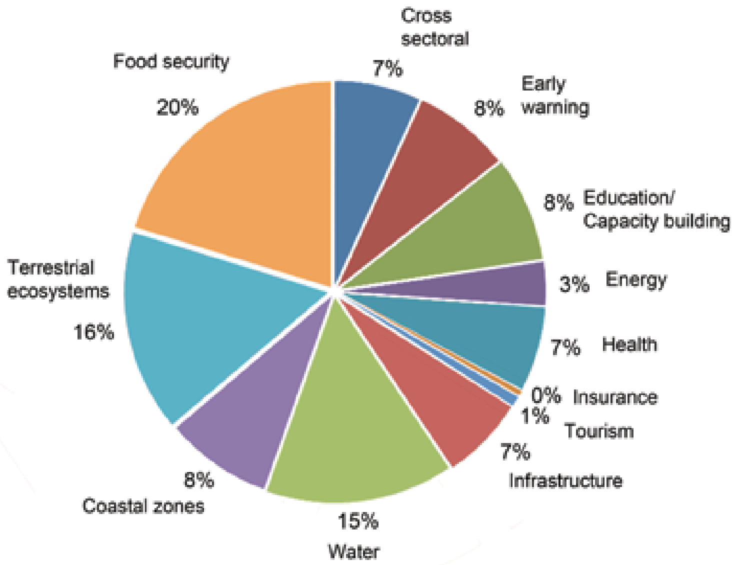

**Figure 1. Distribution of projects by sector**
*Source* : UNFCCC (2011).

Projects are classified according to 12 ”categories” defined by the UNFCCC (Figure 1). According to this categorization, food security is the first category, with 20 percent of the projects, followed by terrestrial ecosystems (16 percent) and water (15 percent).

A closer analysis of what falls within such categories shows that, in fact, most the underlying projects (even outside the “food security” category) are “*mainly related to agriculture*”, in the sense that they either take place within, are directly linked to, or have their main component in the agriculture, including forestry and fisheries, sector.

This is the case for most of the projects classified within the “terrestrial ecosystems” and “coastal zones” categories. The majority of the projects classified as “water” are related to irrigation, and some of them to water quality and drinking water supply. The projects classified as “cross-sectoral”, “early warning” and “education/capacity building” generally cover agriculture. In the “infrastructure” category, 40 percent of the projects are linked to water management and irrigation. The two projects on “insurance” cover agriculture. Some of the “energy” projects are *de facto* in the agriculture sector (including forestry). In the “health” category, the projects for prevention of water-borne diseases, especially for monitoring and control of vector diseases and human diseases related to the risks associated with climate change, have links with animal diseases and agriculture. However, we decided that these links, though sometime very concrete, were too indirect to label these projects as mainly relevant to agriculture.

We compile in Figure 2 the distribution of projects as per the 12 UNFCCC categories, further distinguishing those that are ”*mainly related to agriculture*” from those that are not (as per the methodology described above, with concrete examples further provided in section 3).

## 3. MAPPING OF NAPA PROJECTS MAINLY RELATED TO AGRICULTURE

It derives from the analysis above that the current UNFCCC categorization used in the NAPAs does neither really reflect the share of agriculture-related measures within priority

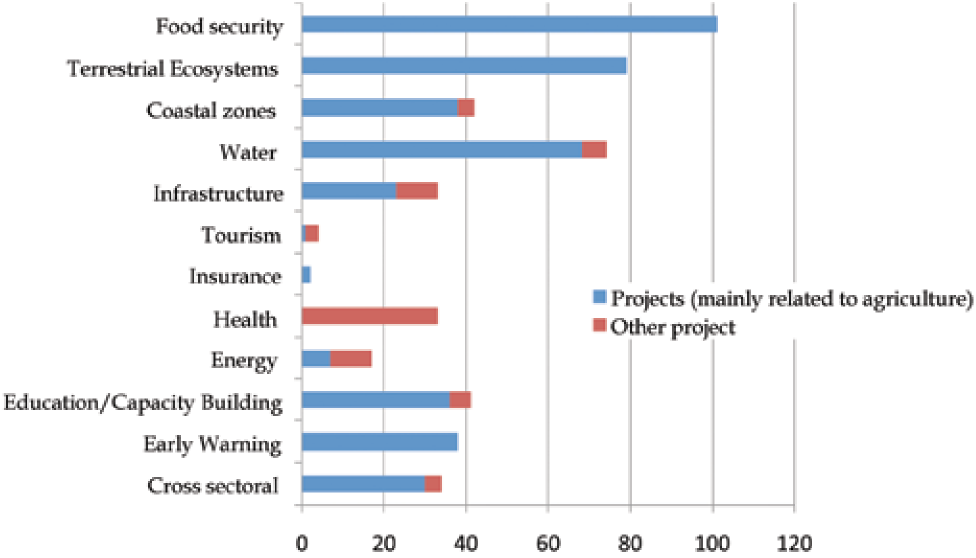

**Figure 2. NAPAs priority projects *mainly related to agriculture* in each of the 12 UNFCCC categories**

adaptation measures, or their main orientation or main aim. Here we propose a more relevant grouping of measures and grid of lecture of NAPAs actions, identifying five main areas of relevance for agriculture-related actions in NAPAs, adapted from the 12 UNFCCC categories.

### 3.1 Cross-sectoral resilience projects

In this category, we have gathered the projects classified within the UNFCCC categories “cross sectoral”, “early warning systems and disaster management” and “education and capacity building”. They have in common the aim to build resilience at community level by improving risk management especially by better information, monitoring, early warning and prevention. Most of them are highly relevant to agriculture.

Many projects are aiming to improve meteorological and hydrological information for both forecasting (generally in the “cross-sectoral category”) and early warning. They include early warning systems on climate, drought, floods, natural disasters and food security.

Others are aiming to adaptation at community and/or landscape level by developing community-based management and integrated management of natural resources, especially of land. In that respect, there is a particular attention in the education and capacity-building measures towards local authorities, aimed at better integrated climate change issues in policies and development planning, including for planning and zoning in order to prevent impacts of climate change and particularly of natural disasters (floods). There is also a focus on vulnerable communities, households and farmers.

Less often are included projects specifically to build disaster management preparedness, strategy and response capacity.

### 3.2 Management of ecosystems

Most of the “terrestrial ecosystems” and “coastal zones and marine ecosystems” concern either integrated management for building resilience at ecosystem or landscape level or management of a particular resource in order to improve resilience of ecosystems and landscape. Again, most of them are highly relevant to agriculture.

For terrestrial ecosystems, projects include: watershed management and restoration; landslide and flood prevention; restoration and management of wetlands and lakes; erosion control; soil conservation; and restoration of degraded land. Forestry plays an important role, as an object for dedicated projects, for instance in projects such as assistance to the implementation of community-based forest management plans or community-based forest fire management and prevention. It is also very often called upon in integrated projects to improve watershed management, prevent soil erosion, landslides and flood. Sustainable management of forests appears thus both as an objective in itself – a way to improve resilience of livelihoods – and also an essential tool to improve resilience of ecosystems and landscapes.

The projects for coastal zones and marine ecosystems include restoration and integrated management of coastal areas, and measures aimed specifically at threatened ecosystems such as mangroves, coral reefs and dunes, which also play a fundamental role in the protection of coastal areas. Some projects aim to improve marine ecosystems management and productivity. There are also projects to improve fisheries management[3] and increase fish production, which are included in the UNFCCC food security category.

### 3.3 Water management

The majority of the projects on water resources are either integrated or specifically linked to water management and efficiency for agriculture and/or hydrological management. A number of projects concern better hydrological management, including for prevention of floods. The majority of the projects in the “infrastructure” category are concerned with water (irrigation, dams, canals).

Irrigation is an important issue with projects on improvement of irrigation systems, dams and reservoirs and better management of groundwater for irrigation (including wells). Some projects on irrigation or supplemental irrigation are classified in the “food security” category. Some projects, particularly in arid areas in small island states (SIDS), concern rainwater harvesting and retention for cultures and livestock.

There are also projects about water quality and drinking water supply, especially SIDS and in some areas to protect water quality against agricultural pollution. Water quality is also the object of several projects classified in the health category.

### 3.4 Plant production and livestock

With respect to plant production, the food security category includes projects on irrigation and supplemental irrigation and on soil conservation.

Numerous projects concern the use of genetic resources to adapt cultures to changing conditions: short-cycle crops, drought-, flood- and salinity-tolerant crops. They cover all

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[3] For more information on the Fisheries and Aquaculture sector in NAPAs, see Vadacchino, De Young and Brown (2011).

the stages of genetic resources management, from conservation and research to transfer (see Box 3), multiplication of improved seeds and access for farmers.

Numerous projects aim to improve agricultural management and practices for sustainable intensification and increased resilience to variability, drought or salinity. They often take the form of integrated projects aiming also for increased and more resilient incomes, in particular through diversification of production (see 3.5).

The projects on livestock mainly cover two types of issues: increasing resilience of livestock systems and especially pastoral systems; and the use of livestock to increase the resilience of farming systems and associated livelihoods.

Adaptation of livestock systems covers issues such as pastoral area management, livestock mobility, improvement of fodder crop species in pastoral areas and on natural routes, improvement of the digestibility of fodder, fodder production and stocks, livestock feed banks, and genetic improvement of local breeds.

Promotion of livestock production and especially of small livestock is often part of integrated projects to better use resources, provide additional income and increase resilience of farming systems and households.

## 3.5 Diversification and income

Various projects, scattered among the various categories, aim to increase resilience of farms and households through diversification. Some of these are included in the food security category such as those related to agricultural diversification, integration of crop and livestock systems, integration of aquaculture, diversification and intensification of production. Some projects have the objective of increasing the value added through processing, marketing and promotion. Others go further, to the promotion of secondary professions and income-generating activities different from agriculture.

The energy category includes projects to improve energy efficiency, promote the development of renewable energy to protect forests and as a way of diversifying production and also reduce costs and dependence on external energy.

Among the projects aiming to increase economic resilience at farm and household level figure the insurance projects, both of which include agriculture.

**Box 3: Introduction of salt-tolerant pulaka species in Tuvalu**

In the Pacific islands of Tuvalu, domestically grown food remains the main source of nutrition, with pulaka, (a root similar to taro) playing an important role as staple crop. However, increasing saltwater intrusion has destroyed more than 60 percent of pulaka pit plantations in Tuvalu, and the remaining 40 percent remain highly sensitive to saltwater intrusion. It is assumed that an absolute destruction of pulaka crops is imminent in the near future for all islands of Tuvalu – possibly in the next decade – which would increase dependence on imports and have important nutritional consequences. To avoid it, the National Adaptation Plan of Tuvalu plans to introduce a salt-tolerant pulaka species in the region.

## 4. CONCLUSIONS

We have shown that agriculture, intended as agriculture, forestry and fisheries, is very prominent in the NAPAs. Most of the measures are, in fact, directly related to the agriculture sectors. As these are the priority measures selected by the countries themselves, after an evidence-based process involving stakeholders, it shows without doubt that adaptation to climate change in LDCs is first and foremost adaptation of agriculture.

Although country-specific, these projects, taken all together, cover the broad range and various ways to increase the resilience of agriculture (see other papers in the proceedings of this FAO workshop). As such, they constitute an extremely valuable base to identify priority areas of work and of research in order to better answer the needs of the most vulnerable. They also provide, when taken together, a database of measures, to be used for the preparation of the National Adaptation Plans as decided in Cancun. Being the priority projects of the most vulnerable countries, they can help design some of the measures that will be needed in the medium term in less vulnerable countries.

And, even more importantly, such priority projects of the more vulnerable countries can more generally be relevant for the prioritization of the investments to be realized for food security and agricultural development in the context of climate change. As underlined by numerous studies and reports, there are huge needs for investments in agriculture and developing countries, particularly when climate change adaptation has to be figured in (Moorhead, 2009; Nelson *et al.,* 2009; 2010; FAO, 2010). These reports and others (Vermeulen *et al.,* 2010) also describe ways for adaptation. The NAPA priority projects can help prioritize action.

This summary review of the sum of projects related to agriculture in the NAPAs shows a great variety of measures aiming at increasing resilience by various angles, at different scales (landscape, community, farm, household) and in different domains. Although they are priority projects, aiming to answer the most immediate needs of the most vulnerable countries, most of them are also very relevant in the medium to long term. Even if each of these projects is contextualized and has been designed to answer specific needs and vulnerabilities, to a great extent their sum, and the fact that they have been designed in country-led processes, with the involvement of stakeholders, forms a unique illustration of the very idea of "how to understand and build resilience for adaptation to climate change", covering various ways and constituting a valuable base and tool box.

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# The role of the International Treaty on Plant Genetic Resources for Food and Agriculture

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## INTRODUCTION

Crop diversity is essential for achieving food security and alleviating poverty. Farmers have always relied on crop genetic diversity to evolve patterns of production and respond to socio-economic and ecological changes.Plant genetic resources are the raw materials for breeding the next generation of crops to respond to the biotic and abiotic stresses brought about by climate change. Nations are already interdependent in terms of their crop diversity; all depend on the genetic diversity from other countries and regions. The world's agriculture is now dangerously reliant on a narrow genetic base of a limited number of food crops, as much of the crop diversity was permanently lost to the world in the last century. The International Treaty on Plant Genetic Resources for Food and Agriculture (International Treaty) has been established as a direct response to these global challenges.

This paper describes the relevance of the International Treaty for building resilience to climate change and introduces relevant work being undertaken by the Governing Body of the International Treaty. It focuses on the work of the Benefit-sharing Fund (BSF) of the International Treaty. More information about the BSF and its relevance to climate change adaptation can be found in the background study prepared by authoritative experts in 2010.[1]

The work of the International Treaty is complementary to other international efforts being made by FAO on managing agricultural biodiversity to respond to climate change.[2] Recently, the intergovernmental Commission on Genetic Resources for Food and Agriculture agreed on the need for a roadmap or work programme on climate change and genetic resources for food and agriculture based on the following four main elements:

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[1] Expert advice on the second call for proposals, including a strategy and programme for the BSF. The paper contains a brief presentation of the professional and scientific background of each of the experts engaged by the Secretary (ftp://ftp.fao.org/ag/agp/planttreaty/funding/experts/bsf_exp_p01_en.pdf).

[2] In 2008, FAO organized a technical workshop on climate change and biodiversity for food and agriculture together with the Platform for Agrobiodiversity Research and the Secretariat of the Convention on Biological Diversity. The outputs of this workshop contributed to the High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy (http://www.fao.org/foodclimate/expert/em8/en/).

strategies and policies; tools and technologies for genetic resources and climate change; forging partnerships; and monitoring progress.[3]

## Climate change in agriculture: the unique role of plant genetic diversity

At least since the release of the 4th Report of the Intergovernmental Panel on Climate Change (IPCC) it is globally accepted that climate change is an unequivocal fact. Its impacts are already perceptible today and will intensify over the current century. According to the IPCC, the global average temperature will rise between 1.8 and 4 °C by the end of the century (compared with an increase of about 0.75 °C over the past century). Global and regional weather conditions will become more variable, with more frequent extreme events, expansion of areas with high climate variability and significant changes in precipitation patterns.

The impact of climate change on agriculture will vary from region to region. Generally, changes in precipitation and rising temperatures are likely to lead to increased incidence and intensity of weeds, pests and diseases in cultivated areas. Higher temperatures are expected to increase the length of the growing season and the total area suitable for cultivation in temperate latitudes, especially in Europe and North America. However, possible yield gains in these regions have to be set against losses owing to the spread of weeds, pests and diseases. Regions in lower latitudes will be most severely affected by a decline in land suitable for cultivation, especially sub-Saharan Africa and the Caribbean. In tropical and subtropical regions, extreme seasonal heat is expected to severely lower agricultural outputs.

Whatever the overall impact, one thing is clear: climate change will profoundly alter the present conditions of agriculture in almost all countries. Projections indicate that by 2050 many countries – making up about 35 percent of the global land area – will experience novel climates they have not been exposed to within their borders before. This suggests that climate change is happening so fast that crops and forage varieties in these areas are very unlikely to adapt to it on their own. Crops that have historically been doing especially well in a given region may no longer be of use and will have to be substituted by other crops: in many areas of sub-Saharan Africa, for example, where maize is a major staple food crop at present, the land may no longer be suitable for its cultivation by 2050.

Besides substituting and introducing new crops, there is an increasing urgency for adapting crop varieties to future climate conditions. The development of varieties with greater tolerance to drought, flooding and extreme temperatures, as well as resistances to pests and diseases, is key in the context of climate change. Because of the likelihood that climate change will result in future growing conditions beyond the parameters in which local crop diversity has developed, adaptation breeding will increasingly require access to appropriate crop genetic resources from outside national borders. Exchange of crop genetic material among countries is thus of paramount importance for climate change

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[3] More information can be found in the Report of the Thirteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture: http://www.fao.org/docrep/meeting/024/mc192e.pdf . The background documentation for the meeting can be accessed at: http://www.fao.org/nr/cgrfa/cthemes/climate- change/en/

adaptation. As future climate conditions are not entirely predictable, it is crucial to conserve as wide a spectrum of crop varieties as possible and to secure a genetic base that is in itself as broad as possible.

Once a crop variety or its wild relatives are extinct, its particular traits – which might become vital for future climate change adaptation – will be lost forever.

### The interlinkages between crop diversity, food security and climate change

Crop diversity, food security and climate change are closely linked in diverse and complex ways. In fact, the world is facing a triple challenge that consists of countering the loss of crop diversity and using it more effectively to achieve and maintain food security under the growing pressures of climate change. Agricultural crop varieties, and the particular traits they contain, form the very base of our food security. In this sense, crop diversity is a precondition for food security, so the challenge of food security cannot be met if crop diversity is not conserved.

The challenge of food security consists of simultaneously lifting one billion people out of poverty and hunger while increasing global food production to meet the needs of a larger and wealthier world population. New plant breeding strategies will therefore have to aim at improving economic and environmental sustainability by developing crop varieties that produce higher yields with less use of expensive and potentially harmful industrial inputs. All of this will place increased demands on the availability of a wide range of crop genetic material.

While climate change is one of the drivers of crop diversity loss, it is also an important reason to conserve agricultural crop varieties, exchange them and use them in a sustainable way. The broader the genetic base our civilization can rely on, the better equipped it will be to adapt to changing climate conditions and to guarantee global food security. But there is urgency to act: whereas climate change is occurring at a fast pace, the process for breeding a new crop variety may take from seven up to 15 years.

### The International Treaty

The International Treaty on Plant Genetic Resources (ITPGRFA) involves 126 Governments and the European Commission working together as Contracting Parties to use crop diversity for food security.

The International Treaty has established itself as the global leader in responding to the challenges of crop diversity preservation, global food security and climate change adaptation. It is in fact the only operational international agreement of a legally binding nature with the overall goal of achieving global food security through the management of crop diversity. The International Treaty provides an effective policy response to global challenges through:

- its comprehensive provisions providing guidance to countries regarding the measures and activities to be undertaken at the national level for the conservation and the sustainable use of crop diversity;
- its provisions on Farmers' Rights which aim at supporting farmers and local and indigenous peoples in conserving crop diversity on their farms;

- the Multilateral System that facilitates access to a global gene pool of crop genetic resources for agricultural research and breeding of new crop varieties that may achieve higher yields and nutritional values and that are adapted to new climate conditions; and,
- the Leading the Field initiative and its BSF that supports initiatives for the conservation and the sustainable use of crop diversity in developing countries, with a focus on helping ensure sustainable food security by assisting farmers adapt to climate change.

The following sections describe how the key operational systems of the International Treaty are supporting climate change adaptation.

## THE MULTILATERAL SYSTEM OF ACCESS AND BENEFIT-SHARING TO PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE: RELEVANCE TO CLIMATE CHANGE ADAPTATION

Global interdependence with regard to plant genetic resources for food and agriculture (PGRFA) will increase as a result of climate change, and the wide, international exchange of agricultural genetic materials will become ever more necessary (see Fujisaka, Williams and Halewood, 2009). Many agroecological zones, and sometimes whole regions, will be unable to ensure food security with the crops and varieties they currently grow and will be forced to rely on resources from elsewhere, often from abroad. In turn, the resources these areas currently hold are likely to be of great importance for farmers in yet other areas (Burke, Lobell and Guarino, 2009). The International Treaty is an instrument that is uniquely designed to promote and facilitate such essential international germplasm exchanges.

With a fully operational multilateral system that has established an ever-expanding global gene pool of more than 1.2 million samples, the Treaty will continue to facilitate the exchange of the vital material needed to enhance farmers' resilience to climate change. In addition, the Treaty's implementation is supported by an extensive network of institutions in more than 127 countries, as well as with significant prior partnerships with FAO, CGIAR and the Global Crop Diversity Trust in support of Treaty implementation.

The gene pool of the multilateral system consists of samples of genetic material from a set of crops, which are listed in Annex 1 to the Treaty. Samples are included in the gene pool by the contracting parties to the Treaty (that is, the governments) and the institutions that they control. Samples also come into the gene pool from international institutions, such as the international gene banks of the Consultative Group on International Agricultural Research (CGIAR), as well as from natural and legal persons, i.e. anyone within the jurisdiction of the contracting parties. These samples are pooled in that they are administered under a common set of rules. These rules are contained in the Treaty and further specified in a contractual instrument, namely the Standard Material Transfer Agreement (SMTA). The rules apply to individual transfers of these samples (for example, from a gene bank to a breeder) for certain purposes, namely utilization and conservation for research, breeding and training for food and agriculture. The rules regulate not only how to obtain access to the plant genetic material but also how to share the results of research and breeding on that material.

In practice, the multilateral system works as a common pooling, distributing and benefit-sharing system for the genetic material that it covers. Access to such resources is facilitated in the sense that those who want to access the genetic material in the system do not need to negotiate access agreements on a case-by-case basis with national competent authorities. Instead, the resources are available to anyone who wants them under a standard contract, the SMTA. The use of the SMTA cuts out all the costs involved in the bilateral process, including the negotiations, legal contracts and other transactions, for the benefit of farmers and gene bank managers, who typically provide the genetic material, and for the plant breeders and researchers who typically seek access to this material to develop new climate-ready plant varieties.

As much as access is multilateral, so is benefit sharing. Since genetic material in the multilateral system is treated as pooled goods, there is no individual owner with whom individual contracts for access and benefit sharing must be negotiated. As such, benefits resulting from their use do not go back to the provider but, rather, must be shared in multilateral ways.

## THE BENEFIT-SHARING FUND: "LEADING THE FIELD" IN CLIMATE CHANGE ADAPTATION

The International Treaty leads the "Leading the Field" initiative by creating a multilateral fund referred to as the BSF, supported by member governments, the private sector and international foundations. This multilateral fund is currently supporting high-impact projects aimed at keeping farmers ahead of the climate change challenge and food secure. The operation of the initiative is facilitated by the Treaty that issues a call for proposals supported by the Treaty's extensive network of National Focal Points in more than 126 countries.

The Governing Body, at its second meeting in 2007, identified three priority areas for support from the BSF (FAO, 2007), building on the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture:

- information exchange, technology transfer and capacity-building;
- managing and conserving plant genetic resources on farm; and
- the sustainable use of plant genetic resources.

### Thematic focus

There is widespread agreement that one of the areas of greatest concern currently confronting agriculture is how to ensure sustainable food security in the face of climate change. The Declaration of the World Summit on Food Security (FAO, 2009), for example, states in paragraph 5:

> *"Climate change poses additional severe risks to food security and the agriculture sector. Its expected impact is particularly fraught with danger for smallholder farmers in developing countries, notably the Least Developed Countries (LDCs), and for already vulnerable populations. Any recipe for confronting the challenges of climate change must allow for mitigation options and a firm commitment to the adaptation of agriculture, including through the conservation and sustainable use of genetic resources for food and agriculture."*

Following the World Food Summit, at the invitation of the Italian Government, international experts met in Bari, Italy, in December 2009, at a Policy Seminar on the International Treaty on Plant Genetic Resources for Food and Agriculture: Global Challenges and Future Direction. The participants stressed the importance of PGRFA in responding to food security challenges resulting from climate change. Because of the importance and urgency of taking steps to help agriculture adapt to climate change, the Seminar recommended that the BSF should, in the near future, focus on climate change adaptation and plant genetic resources.

These recommendations are also consistent with the First Assessment Report of the IPCC (IPCC-FAR), which indicated, albeit without much detail, the need for, and possibilities of, breeding improved varieties of key staple crops to help meet the impact of climate change (Easterling *et al*., 2007). A recent publication by Lobell (2009) reported that there is a growing consensus among agriculturalists that the development of new varieties will be critical for successful adaptation to climate change.

In this context, the Bureau of the Governing Body of the International Treaty requested the Secretary to seek expert advice on a strategy and programme for the BSF. This expert advice, which was the basis for the Call for Proposals 2010 of the BSF, was prepared by a team of leading international authoritative experts in the fields of genetics and climate change (see footnote 1).

The high-level experts agreed that the major thematic focus of the BSF, at least over the coming years, should be on the conservation and use of PGRFA to help ensure food security in the face of climate change. Notwithstanding the concerns cited above, to date relatively little attention has been given to this subject nationally or internationally and there is only limited scientific information on the topic. The IPCC-FAR assessment provided only scant information on the impact of climate change on genetic resources and on the role of genetic resources in helping agriculture adapt to climate change.[4] While the Copenhagen Climate Summit recognized the relationship between climate change and agriculture and food security, no major international programme has yet been mounted to counter the threat. The field is thus wide open and much remains to be done. It is, therefore, highly appropriate that the BSF should take a leading role in initiating a major global programme to address this issue, in particular focusing on the use of genetic resources in helping agriculture to adapt to climate change for the benefit of the most vulnerable farmers and rural populations.

The experts recognized that the International Treaty, because of its mandates and operational systems, is exceptionally well placed in the international policy landscape to create such a programme, but it cannot act alone or in isolation. The work needs to be carried out through close collaboration with a wide range of stakeholders and partner organizations – and fortunately there are substantial opportunities for such cooperation. While, in line with the Governing Body's priorities, the primary beneficiaries of the programme should be vulnerable farmers and rural communities in developing countries, and a principal focus

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[4] It has been suggested that the International Treaty might consider commissioning a review of the scientific evidence relating climate change with PGRFA and make this available as an input to the 5th IPCC Assessment Report.

should be at the local and national levels, it will also be important to work with regional and international partners who bring similar and complementary resources and skills to address the problem. Potential partner institutions at the international level include, for example, the United Nations Framework Convention on Climate Change (UNFCC), the United Nations Development Programme (UNDP) and the Convention on Biological Diversity (CBD) as well as the CGIAR centres, the Program on Climate Change, Agriculture and Food Security (CCAFS). Furthermore the Global Crop Diversity Trust is already funding climate change activities in relation to ex-situ conservation and there is a large potential for developing integrated and coordinated activities linking ex-situ conservation to use and in-situ conservation, funded through close collaboration between the Trust and the BSF.

## Implementation of the thematic focus

Enabling farmers to adapt to climate change is a medium- and long-term activity that requires the development and regular update of strategic plans and, based on these, the proactive development of the means to adapt, before irreversible disasters occur. Activities should not be piecemeal, but conceived and implemented within the framework of overarching strategies. Such a strategic approach would also greatly facilitate the mobilization of the necessary financial resources by the Treaty, and provide the basis for the development of cooperation between the Treaty and other relevant funds, institutions and programmes.

The BSF is operating in two overlapping phases: first, the development of overarching strategic plans and second, a role-out, or implementation phase. The first phase (that would occur in parallel with some initial ‘quick win’ projects) would fund, through projects, analyses of the challenges posed by climate change and opportunities for meeting these challenges, through the development of spatially appropriate priorities, strategies and action plans. The second phase would fund specific projects to implement these strategies and priorities. The strategic plans should provide the framework in which activities supported by the BSF can be developed and future Calls for Proposals articulated.

It is likely that applicants will both require, and seek, some kind of technical support to assist them to develop proposals, especially with regard to development of strategic plans. It would thus be highly desirable for the Treaty Secretariat to draw upon existing institutions and programmes that support the implementation of the Treaty to facilitate technical assistance and coaching through a Help Desk function to applicants, upon request.

## Strategic plans

While much of the individual action within projects is expected to be targeted locally and nationally, in order to capture synergies and complementarities, and recognizing the shift of agro-ecological zones that will occur with climate change, strategic plans should set out clear priorities and action plans on a regional, subregional, ecoregional, or other basis.[5] For example, strategic plans could focus on agro-ecological zones, such as the marginal dry lands of the sub-Saharan Africa region, southern Africa, tropical mountain areas or Asian flood

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[5] This might include, for example, strategic plans formulated on the basis of specific crops or crop group (cereals, food legumes, vegetables, etc.).

plains and coastal saline areas – all areas where the IPCC-FAR has predicted major disruptions will occur as a result of climate change (Parry *et al.*, 2007). A pragmatic approach that makes it possible for relatively large-scale integrative strategies to be developed, and within which groups of potential recipients can jointly find a role, will be needed.

The BSF is, at least initially, aiming to fund the development and implementation of strategic plans through existing national, regional and international institutions, through existing national and regional networks where these are effective, or through encouraging the creation of new consortia or other multistakeholder groupings. The identification of coherent and representative recipient groups to carry out the work, with clearly defined roles and responsibilities agreed among the partners concerned, should be a priority for the BSF. It is expected that in many cases these consortia or multistakeholder groups would continue in existence beyond the development of the strategic plans and have a role in their implementation.

Ideally these strategic plans are integrated or coordinated with broader local, regional, national and international agriculture and/or climate change adaptation strategies and action plans. They would be implemented as part of broader approaches to low emission, climate resilient development. This would have the advantage of leveraging synergies in both action and financial resources.

### Implementation/immediate action projects

Projects to implement the strategic plans should involve multiple stakeholders from different sectors. Most projects are expected to be international in scope and may involve institutions and individuals from several countries and from local, national and international organizations.

In order to have the desired impact, implementation projects are substantially larger and more comprehensive than the 11 small-scale projects supported in the first cycle.[6] Target beneficiaries and the expected outputs and outcomes of the projects should be identified and impact pathways and milestones, including verifiable indicators of success, should be made clear from the outset.

Given the importance of the materials developed as a result of investment by the BSF, all such material arising from projects funded by the BSF, including any that are not included in Annex 1 or Article 15 of the Treaty, should be made available through the multilateral system of access and benefit sharing under the International Treaty.

Implementation/immediate action projects supported in this next round demonstrate, in addition to the selection criteria approved by the Governing Body:

a) that they address the major goal of achieving sustainable food security through the conservation and use of PGRFA to assist farmers to adapt to climate change;
b) that they have the potential for a short-term impact (‘quick win’);
c) that they respond to a clear priority need, as expressed through already existing strategies or plans; and
d) that they are country-driven and demonstrate a clear engagement with, and participation by, relevant stakeholders.

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[6] See ftp://ftp.fao.org/ag/agp/planttreaty/gb3/gb3i11e.pdf

### Current project portfolio of the Benefit-sharing Fund: Call for Proposals 2010

Following the expert advice, a unique global competitive process was launched by the Bureau of the Governing Body of the Treaty to select a portfolio of projects based on quality and technical merit. More than 300 institutions participated in the competition and an independent Panel of Experts undertook the appraisal of more than 100 full proposals. The Panel consists of independent regional experts selected from a roster of experts on plant genetic resources, climate change adaptation and rural development.[7]

The Benefit-sharing Fund is now disbursing around USD6 million in projects approved for immediate funding from the Benefit-sharing Fund. There are 14 country projects and five multicountry projects approved, in 34 countries participating in four FAO Regions (Africa, Asia, Latin American and Caribbean countries, Near East). The project portfolio promotes innovative planning and adaptive solutions for the intertwined challenges of food insecurity, climate change and biodiversity loss. This portfolio will enable the Treaty to generate a unique global understanding on key priorities for training, capacity building and technology transfer in the sustainable use of the crop diversity that feeds the world and will make agriculture resilient to climate change.

Projects support vulnerable farmer and rural communities in at least one of the following geographic areas:

- centres of origin or diversification of cultivated plants;
- areas with high levels of rural poverty or food insecurity of targeted countries;
- regions where climate change is severely affecting food security and agriculture in the next decades.

Examples of non-profit groups being funded include:

- governmental: the national biodiversity centre of Bhutan and the Indonesian biotechnology centre;
- partnerships: among universities, non-governmental organizations (NGOs) and an international research centre in Near East (Syrian Arab Republic, Jordan, Iran) and Africa (Ethiopia);
- non-governmental: a community-based platform working in 11 countries or a local NGO working with smallholder farmers in Guatemala.

## CONCLUSIONS

Given its potential to contribute to coping with climate change, the sustainable management of biodiversity for food and agriculture should be made a basic component of strategies dealing with climate change adaptation in the rural sectors. Still, biodiversity for food and agriculture and climate change have rarely been discussed in the same context. There is a need to improve cooperation between the United Nations Framework Convention on Climate Change and relevant biodiversity forums, such as the International Treaty.

The International Treaty that has been established as a direct response to global challenges such as climate change is now a fully operational global system. It provides

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[7] For more information on the Panel of Experts see: http://www.itpgrfa.net/International/content/members-panel-experts-call-proposals-2010

multilateral mechanisms for facilitating access to the genetic diversity needed to enable climate change adaptation and for enabling benefit sharing directed to address global challenges through local impact. The Treaty provides a unique policy forum of the United Nations to advance international cooperation in the conservation, exchange and use of the crop diversity so crucial to feed the world at a time of climate change.

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# Crop production in a northern climate

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## CONCEPTS AND ABBREVIATIONS USED IN THIS THEMATIC STUDY

In this thematic study *northern growing conditions* represent the northernmost high latitude European countries (also referred to as the northern Baltic Sea region, Fennoscandia and Boreal regions) characterized mainly as the Boreal Environmental Zone (Metzger *et al.*, 2005). Using this classification, Finland, Sweden, Norway and Estonia are well covered. In Norway, the Alpine North is, however, the dominant Environmental Zone, while in Sweden the Nemoral Zone is represented by the south of the country as for the western parts of Estonia (Metzger *et al.*, 2005). According to the Köppen-Trewartha climate classification, these northern regions include the subarctic continental (taiga), subarctic oceanic (needle-leaf forest) and temperate continental (needle-leaf and deciduous tall broadleaf forest) zones and climates (de Castro *et al.*, 2007). Northern growing conditions are generally considered to be less favourable areas (LFAs) in the European Union (EU) with regional cropland areas typically ranging from 0 to 25 percent of total land area (Rounsevell *et al.*, 2005).

*Adaptation* is the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities (IPCC, 2012).

*Adaptive capacity* is shaped by the interaction of environmental and social forces, which determine exposures and sensitivities, and by various social, cultural, political and economic forces. Adaptations are manifestations of adaptive capacity. Adaptive capacity is closely linked or synonymous with, for example, adaptability, coping ability and management capacity (Smit and Wandel, 2006).

*Resilience* is the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions (IPCC, 2012).

*Vulnerability* is the propensity or predisposition to be adversely affected (IPCC, 2012). It is a dynamic concept, varying across temporal and spatial scales and depends on economic, social, geographic, demographic, cultural, institutional, governance and environmental factors.

*SRES* refers to the Special Report for Emission Scenarios of the Intergovernmental Panel on Climate Change (IPCC).

*A2 forcing scenario* represents a pessimistic scenario of the SRES, anticipating high greenhouse gas and aerosol emissions.

*B1 forcing scenario* represents an optimistic scenario of the SRES, anticipating low greenhouse gas and aerosol emissions.

*GCM* refers to global climate model(s).

*RCM* refers to regional climate model(s).

## 1. INTRODUCTION AND BACKGROUND

In the context of global changes, climate change is one of the greatest challenges facing humankind and terrestrial ecosystems. On a global scale, some of the most considerable and direct impacts of climate change over the next few decades will be on agricultural and food systems (Lobell *et al.,* 2008; Battisti and Naylor, 2009). Increasing global population growth, urbanization and an ever-increasing demand for food, together with rising standards of living in the highly populated regions and the concomitant changes in food consumption towards production-inefficient, meat-intensive diets, are placing unprecedented demands on agriculture and natural resources (Foley *et al.,* 2011; Peltonen-Sainio and Niemi, 2012). To meet the world's future demand for food security and sustainable agriculture, substantial growth in food production must be coupled with dramatic reductions in the environmental footprint of agriculture. Foley *et al.* (2011) anticipate that tremendous progress could be made by halting agricultural expansion, closing yield gaps on less productive land, increasing cropping efficiency, shifting diets and reducing waste.

Agriculture is a sector that is closely linked to climate and that is thereby naturally prone to impacts of climate change. Agriculture in the northern European climate – the focus area of this thematic study – is practised at higher latitudes than elsewhere on the planet (Figure 1) and takes account of many special, even exceptional, features and conditions. It is projected that climate warming will progress particularly fast in the high latitude regions of the northern hemisphere. This means that there is only limited time available for development and implementation of adaptation measures that are essential to improve resilience and adaptive capacity of the northern agricultural sector. On the other hand, prolongation of the currently exceptionally short growing season implies opportunities for yield increases

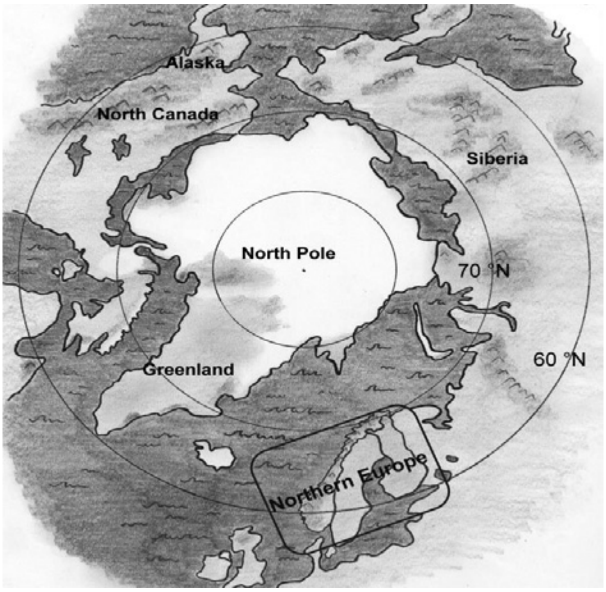

**Figure 1. Northern European growing conditions are exceptional at the global scale. At >60 °N not only grass crops but also large-scale, intensive grain and seed crop production is practised, contrary to the case elsewhere at comparable latitudes**

*Source*: Peltonen-Sainio *et al.* (2009b). *Drawing*: Jaana Nissi/MTT.

and sustainable intensification of production systems in the northern regions. One could even say that by these means climate change takes northern European crop production into a new era. However, fluctuating weather conditions, meaning large inter- and intra-annual as well as spatial variation, are typical for high latitude agro-ecosystems. Therefore, variable conditions have required hitherto continuous adaptation and measures by farmers to manage production risks. Because northern European regions are considered to have major obstacles to agriculture, they are mainly regarded in the European Union (EU) as less favourable areas (LFAs). These refer to agricultural areas that are currently characterized as economically marginal, non-optimal production regions (Rounsevell *et al.*, 2005). In the future, challenges and constraints for northern cropping systems induced by or associated with climate change, are not likely to ease, even though in general production potentials are anticipated to increase substantially (Peltonen-Sainio *et al.,* 2009a). Therefore, northern agriculture is at an interesting but challenging crossroads.

In Europe and its northernmost regions, land use and crop productivity per unit land area are projected to change substantially in the future. The outcome is, however, especially dependent on the rate of progress of technological development (Rounsevell *et al.*, 2005; Ewert *et al.,* 2005). In the case that technology (including plant breeding) continues to progress at current rates, the need for agricultural land in Europe is likely to decline drastically if demand for agricultural commodities does not increase, if agricultural policies do not encourage extensification of vast production areas and/or if overproduction is not accepted, for example, through increasing export of agricultural commodities (Rounsevell *et al.*, 2005). Sustainable intensification through agro-technological development in regions with relatively unproductive lands (environmental conditions allow more efficient agricultural production), such as in the Russian Federation and many eastern European countries, would allow, for example, large-scale production of bioenergy in set-aside fields (Hakala, Kontturi and Pahkala, 2009).

Many alternative future prospects for field use are considered for northern growing areas: yield gap closing, sustainable intensification or, in contrast, extensified production systems. One could argue that the present “semi-extensive or semi-intensive” system is less of an attractive alternative when it comes to yield gains, input use efficiencies and environmental impacts if compared with having both sustainably intensified and fully extensified fields. Depending on future conditions for competitiveness of agricultural production, policy, markets and economic incentives for both intensified and extensified systems could result in combined cropping systems incorporating monocultures, diversified rotations favouring protein crops or other currently minor crops, environment-preserving cover-crops, bioenergy crops and/or naturally managed fields. Thereby, the outcome for future field use will actually determine to what extent northern European agriculture takes responsibility or outsources all the multidimensional challenges related to food production and nature preservation. The fundamental questions regard the focus-areas for production of different agricultural commodities in Europe under changing climates, the risks and opportunities, and how northern European agriculture, which is projected to face drastic and progressive changes in production capacities and systems, will function in the context of European and global food and agricultural systems in the future.

This thematic study characterizes the typical features of the northern European agriculture and climate, it evaluates vulnerability of crop production to climate change at high latitudes, and considers the means to adapt to climate change and improve resilience, productivity and sustainability of high latitude cropping systems in the future.

## 2. NORTHERN EUROPEAN CLIMATE AND CROPPING SYSTEMS

Agriculture in northern European high latitude conditions is possible only due to the Gulf Stream, which, together with its northern extension towards Europe, the North Atlantic Drift, is a powerful, warm and swift Atlantic Ocean current that originates in the Gulf of Mexico and favourably influences the climate of the west coast of Europe (Peltonen-Sainio *et al.*, 2009b). Therefore, northern European temperatures during the growing season are typically higher than elsewhere at comparable latitudes, enabling production of many grass and cereal crops as well as some special crops to a limited extent.

Boreal regions represent conditions that combine many special features and constraints for crop production, such as harsh winters, an exceptionally short growing season, long days during the summer months, generally cool mean temperatures during the growing season, high risk of early and late season night frosts, early summer drought and high risk of abundant precipitation close to harvests (Peltonen-Sainio *et al.*, 2009b). However, not only the general obstacles for northern growing conditions *per se*, but unpredictability caused by substantial fluctuation in conditions, represent biological and economic challenges and risks for farmers when managing cropping systems at the northern margins of global food production. Extreme climatic events may cause total crop failures, averaging one per decade, as documented since the 1960s for Finland (Peltonen-Sainio and Niemi, 2012). In contrast to present day sophisticated agricultural systems and practices and access to world trade, food security and agricultural production under northern European conditions in the past went firmly hand in hand. During recent centuries, insecurity in crop production caused by harsh climatic conditions plunged the population into food shortage, famine and up to 30 percent mortality, as documented for the Finnish population at the end of the 1600s (Peltonen-Sainio and Niemi, 2012).

### 2.1 Weather conditions and constraints

**The thermal growing season** typically starts in mid-April to mid-May and ends by late September to early November, thereby ranging over 125 to 200 days in regions with a significant share of agricultural land in northern Europe (Tveito *et al.,* 2001). Mean degree-days for the growing season (daily mean temperature above 5 °C) range from 800 to 1700 °Cd[1] (Tveito *et al.,* 2001), but only part is utilized for crop production and often less efficiently the further north the region (Peltonen-Sainio, Jauhiainen and Venäläinen, 2009). In addition to spatial differences in mean growing season degree-days, regional differences in probabilities of having growing seasons with different degree-days vary. For example, in Finland, degree-days can range from 800 °Cd to 1300 °Cd within the southeastern region depending on the year (Peltonen-Sainio, Jauhiainen and Venäläinen, 2009).

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[1] Cd = cooling degree.

**Temperature**. Northern European growing conditions are generally characterized as cool. The northernmost agricultural regions in the Boreal Zone (close to 65 °N) have summer temperatures averaging 12 °C, while in southern Finland and Norway mean temperatures approach 16 °C, which represents the average for Estonia and which is exceeded in southern Sweden.

**Precipitation**. The number of days with precipitation ≥1.0 mm ranges from 50–100 to 200, being highest in the western coastal regions of Norway (Tveito *et al.*, 2001). Typically during the summer months accumulated precipitation is low, averaging 40 mm per month in May–July in the Baltic Sea region and thereafter increasing to a maximum of 70–80 mm per month during late autumn. However, differences in distribution of precipitation between and within seasons are high (Kjellström and Ruosteenoja, 2007). In general, precipitation falls unevenly over time and contrary to the requirements of the major field crops. Droughts typically interfere with plant stand establishment and early plant growth and development, which is especially critical for yield formation of spring sown seed crops. Also regrowth of grass crops after the first cut is often retarded by temporary drought.

**Winter conditions**. In northern European conditions the period outside the growing season is long (Tveito *et al.*, 2001). Number of frost days (daily mean temperature below 0 °C), which indicates length of the thermal winter, ranges from 50–70 in the southernmost regions of Sweden up to 150–200 in the northernmost agricultural regions (Tveito *et al.*, 2001; Jylhä *et al.*, 2008). Freezing point days (days with a daily minimum air temperature <0 °C and daily maximum temperature >0 °C) are again typically higher in spring (30–40 days) than in autumn and winter (Jylhä *et al.*, 2008). Snow cover tends to range from less than 90 days in southern Sweden up to 200 days in the northern parts of the Boreal Zone regions with agricultural land (Jylhä *et al.*, 2008). There have been fluctuations in severity of winter conditions when determined according to the extent of Baltic Sea ice. In general some 20 percent of winters were classified as severe or extremely severe in 1902–1990, while some 10 percent were extremely mild (Jylhä *et al.*, 2008).

## 2.2 Special features of northern crop production to cope with

The growing season in northern Europe is characterized by a strikingly low number of effective growing days, i.e. days combining sufficient temperature and water availability with lack of night frosts and snow cover (Table 1) (Trnka *et al.*, 2011). The low number of effective growing days is likely to be the major limitation contributing to the modest yields realized in the northernmost European regions such as Finland (Peltonen-Sainio, Jauhiainen and Hannukkala, 2007; Peltonen-Sainio, Jauhiainen and Laurila, 2009; Peltonen-Sainio *et al.*, 2009b).

Because of a special combination of agro-climatic conditions, crop development, growth and yield determination have many unique features. These call for special mechanisms and approaches when adapting to northern conditions through plant breeding and through crop management tailored to northern agricultural systems characterized by high production risks and uncertainties (Peltonen-Sainio *et al.*, 2009b).

**Table 1: The 5th, 50th and 95th percentile values for agro-climatic indices during 1971–2000 and the estimated changes in the median values for 2030 assuming the A2 SRES scenario according to Trnka *et al.* (2011)**

| Zone | Effective global radiation (MJm$^{-2}$/ year) | | | Effective growing days (days/year) | | | Date of last frost (day of the year) | | | Proportion of dry days in JJA (%) | | | Proportion of sowing days in early spring (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | The experienced period of 1971–2000 | | | | | | | | | | | | | | |
| | 5th | 50th | 95th | 5th | 50th | 95th | 5th | 50th | 95th | 5th | 50th | 95th | 5th | 50th | 95th |
| BOR | 581 | 1 417 | 1 824 | 57 | 115 | 154 | 127 | 146 | 169 | 2 | 31 | 83 | 0 | 5 | 16 |
| ATN | 1 536 | 2 187 | 2 596 | 133 | 190 | 226 | 91 | 117 | 142 | 3 | 14 | 58 | 13 | 30 | 48 |
| CON | 1 693 | 2 296 | 2 812 | 123 | 172 | 212 | 92 | 113 | 135 | 4 | 23 | 55 | 23 | 41 | 60 |
| MDN | 2 161 | 2 795 | 3 434 | 159 | 201 | 242 | 53 | 61 | 100 | 33 | 51 | 74 | 33 | 50 | 65 |
| | Estimated time horizon of 2030 | | | | | | | | | | | | | | |
| | Change (%) | | | Change (days) | | | Change (days) | | | Change (%) | | | Change (%) | | |
| BOR | 3 – 7 | | | 11 – 17 | | | –6 – –4 | | | –6 – 1 | | | 4 – 5 | | |
| ATN | 0 – 3 | | | 3 – 17 | | | –8 – –5 | | | 3 – 11 | | | 3 – 5 | | |
| CON | –3 – 1 | | | ––2 – 5 | | | –7 – –4 | | | 4 – 11 | | | 4 | | |
| MDN | –10 – –2 | | | –11 – –3 | | | –24 – –20 | | | 4 – 9 | | | 1 – 2 | | |

The range for the future estimates is based on three GCMs: ECHAM, HadCM and NCAR. Environmental Zones (Metzger *et al*., 2005) are: BOR, Boreal; ATN, Atlantic North; CON, continental; MDN, Mediterranean North. JJA refers to June––July–August.
*Source*: Peltonen-Sainio and Niemi (2012).

**Crop and cultivar selection** represent a fundamental means for a farmer to cope with prevailing conditions, and especially so in the short northern growing conditions characterized by many special features requiring breeding for strict adaptation. The northern European growing seasons are cool, but in general the average temperatures are favourable for growth and yield formation of cereals, rapeseed (both oilseed rape [*Brassica napus* L.] and turnip rape [*B. rapa* L.]), grain legumes and many other temperate crops. In spite of the fact that crop production is surprisingly diverse in European high latitude conditions when compared with comparable latitudes elsewhere in the northern hemisphere (see Figure 1), cereal and grass crops dominate Boreal agro-ecosystems (Table 2). Typically the proportion of grassland extends from the south to the north, contrary to that of cereals and other crops. Also spring-sown cereals and rapeseed dominate at higher latitudes, as in Finland, while winter types become increasingly common and gradually start to dominate when moving towards the southern parts of Sweden (Peltonen-Sainio *et al*., 2009a). Owing to a low number of alternative, economically feasible crops and to strong fragmentation of agricultural sectors and the south-north dimension (e.g. field crop production concentrated in southern Finland and dairy production in the north), northern European crop rotations are not currently sufficiently diverse to prevent soil compaction (Alakukku *et al*., 2003; Peltonen-Sainio *et al*., 2011) or efficiently prevent or alleviate crop protection risks.

**Sowing**. The growing conditions in Boreal regions often have very narrow windows for favourable sowing time in spring (Table 1) and autumn. In spring, snow has to melt and the fields need to dry to carry machinery without destructive effects on soil structure – but not too dry so as to maintain a favourable combination of soil moisture and temperature for germination (Peltonen-Sainio *et al*., 2009b). In the autumn, drought does not typically

**Table 2: Total agricultural land as well as area under cereal production (ha), temporary and permanent meadows and pastures in Boreal region countries for 2000–2009**

| Country | Total agricultural land 1000 ha | Cereals 1000 ha (%) | Grassland 1000 ha (%) | Others % |
|---|---|---|---|---|
| Estonia | 871 | 287 (33) | 425 (49) | 18 |
| Finland | 2 264 | 1 164 (51) | 668 (30) | 19 |
| Norway | 1 036 | 321 (31) | 656 (63) | 6 |
| Sweden | 3 151 | 1 089 (35) | 481 (15) | 50 |

Proportions of areas for pea (*Pisum sativum* L.), rapeseed, potato (*Solanum tuberosum* L.) and sugar beet averaged <1% from total agricultural land for each crop and country.
*Source*: FAO Statistics (www.faostat.fao.org)

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interfere with plant stand establishment of winter sown cereals, but again the window for sowing is small after harvests of a pre-crop to provide seedlings with sufficient capacity for winter hardening and to be thereby better prepared to resist overwintering damage (Peltonen-Sainio *et al*., 2009b). Abundant autumn rainfall can prevent sowing when fields are not able to carry the machinery. Night frosts occur both in early and late summer. In the early season, night frosts may retard growth of cereals but without lethal effects, contrary to the most frost-sensitive species, rapeseed and sugar beet (*Beta vulgaris* var. *altissima*) that need to be resown after severe night frosts. On the other hand, early season potato plant stands are actively sheltered from night frosts.

**Water availability**. Precipitation is unevenly distributed in northern conditions when compared with requirements of many crops. Early summer drought accompanied by development-enhancing long days often interferes with plant stand establishment and subsequent yield determination (Peltonen-Sainio *et al.,* 2009b; Peltonen-Sainio, Jauhiainen and Hakala, 2011). Early summer drought is particularly damaging for spring-sown crops as overwintered crops can better utilize snow melt water. Furthermore, winter crops have their roots already in the deep soil layers by the start of the growing season, which enables access to water. For example, depending on the region in Finland, only 30–60 percent of the precipitation needed at early summer for undisturbed yield formation of spring barley (*Hordeum vulgare* L.) fell on average over three decades (Peltonen-Sainio, Jauhiainen and Hakala, 2011). Such a water deficit resulted in yield losses averaging 7–17 percent depending on region.

Reduction in yield potential caused by early summer drought cannot be compensated for by higher precipitation later in the growing season, although it generally favours grain filling and results in higher grain weight (Peltonen-Sainio *et al*., 2007; Rajala *et al*., 2011). Lack of compensation capacity in northern conditions is associated with long-day-induced accelerated development and maturity processes of the crops. Because of the uniculm growth habit (i.e. main shoot growth is advanced and favoured at the expense of tiller initiation and growth) of spring cereals induced by long days (Peltonen-Sainio *et al*., 2009c), tillering as a plastic trait cannot compensate for harmful early summer drought effects, which is contrary to the plasticity mechanisms operating at lower latitudes.

Despite water scarcity at critical stages of growth, field crop production is basically rainfed in northern Europe and only horticultural crops are irrigated. Hence, northern European farmers do not currently have the means to cope with water stress other than for conserving soil water content with crop management systems. According to FAO, >1 percent of total agricultural land in Estonia is equipped with irrigation machinery, 4 percent in Finland, 5 percent in Sweden and 12 percent in Norway. Restricted water availability is not only the principal reason for yield losses, but is also associated with low nutrient uptake efficiency. Water deficit has been frequently and severely experienced, for example in Finland in the 2000s. During 2002–2003, 1 400 farms, many with livestock, suffered from water scarcity: over 64 000 m$^3$ of water was transported to farms at average costs of €5/m$^3$. Also yields were low and some 20–40 percent of autumn sowings were re-established. Additional costs to agriculture alone in the extreme southwestern areas were nearly €10 million (Silander, 2004).

In addition to yield losses caused by early summer drought, abundant precipitation at grain-filling may reduce quality and challenge harvests. Owing to late summer precipitation, grains and seeds are always dried before storing. When not causing lodging, post-heading rain may favour grain and seed fill, but it interferes with seed set when occurring at flowering in oilseed rape (Peltonen-Sainio *et al.*, 2010). The harmful effects of late summer rains were, however, recorded across many regions of Europe.

**Overwintering**. Harsh overwintering conditions result in poor winter survival, yield losses or total failures even in the adapted, most resistant crops and cultivars. Severe overwintering damage occurs, and may be lethal when a combination of unfavourable, critical conditions occur together or succeed each other (Hömmö, 1994). Under northern conditions, winter survival is typically dependent on latitude (which is associated with harshness of winters), crop species and winter-hardiness of a particular cultivar.

Low winter temperatures rarely cause crop death as hardened overwintering crops usually tolerate freezing temperatures during winter (Hömmö, 1994; Antikainen, 1996), especially if accompanied by protective snow cover. Abundant snow cover may, however, maintain the temperature range at the plant stand level favourable for infections by low-temperature parasitic fungi (Ylimäki, 1969; Hömmö and Pulli, 1993; Nissinen, 1996; Serenius *et al.,* 2005). Melting of snow, especially in spring when the number of freezing point days is at its highest, can result in formation of hermetic ice cover ("ice encasement") that causes anoxia, i.e. impeded oxygen flow for crop maintenance respiration (Hofgaard *et al.,* 2003). Freezing point days may also cause freezing of the uppermost soil layers, and thereby root breakage. Carbohydrate reserves may be insufficient for long-lasting winters, or if winters are exceptionally warm, which enhance crop metabolism (Niemeläinen, 1990; Antikainen, 1996; Hakala and Pahkala, 2003).

The degree of risk and uncertainties that are associated with growing winter cereals and rapeseed depends on region, being highest in the north. When excluding grasslands, high overwintering risks in general can be seen as negligible or modest growing areas for winter crops, especially in the northernmost Boreal regions when compared with areas in central and southern Europe. Also, large differences are apparent for sown and harvested areas over years. Choosing spring cereals over winter types allows farmers to reduce production risks at high latitudes. Severe winter damage in one year has been demonstrated to result in decline in sown areas of winter cereals in the subsequent year (Peltonen-Sainio, Hakala and

Jauhiainen, 2011), indicating that farmers are risk- averse. Another example of adaptation measures is that winter cereals are often sown on sloping fields to aid surface water run-off from the fields and thereby reduce risks for formation of hermetic ice cover. Late sowing is used to avoid formation of dense canopies before winter, as is use of cultivars resistant to pathogens to avoid winter damage (Serenius *et al*., 2005). For susceptible winter cereals, especially in the northernmost areas with deep and long-lasting snow cover, plant protection measures against fungal infections are often needed to cope with the overwintering risks represented by fungal pathogens (Serenius *et al*., 2005).

**Crop protection**. Risks of pest and disease outbreaks are lower in northern, cool climates with short growing seasons and long winters, when compared with more southern agricultural regions in the northern hemisphere. Cool climates hold back reproduction and the number of generations of pests and diseases per season (Hakala *et al*., 2011). Therefore, use of agro-chemicals is generally modest. However, there are many examples of how recent changes in farming, farm structures and cropping systems are driven by political, economic and environmental motives, and summers with warm spells, drought and stressed plant stands have highlighted the harm caused to crop production through reduced farmer awareness and insufficiency in their crop protection measures (covering the whole range, from preventative actions to chemical control).

## 2.3 Production uncertainties and extreme events

Depending on outcome of the climatic constraints and other production risks related to northern climates, as well as farmer capacity for risk avoidance, substantial fluctuations in production quantities and qualities are apparent for northern conditions (Peltonen-Sainio, Jauhiainen and Hakala, 2009; Peltonen-Sainio *et al*., 2009b; Peltonen-Sainio and Niemi, 2012). Fluctuations in weather conditions affect both economic and environmental sustainability of agricultural production. For example, spatial and temporal differences in frequency and abundance of precipitation may result in inadequate uptake of nitrogen, low removal rate of applied nitrogen and increased risks of nutrient leaching (Rankinen *et al*., 2007; Peltonen-Sainio and Jauhiainen, 2010). Such a high risk of leaching into natural water systems has been addressed by the Agro-Environment Program through reducing nitrogen fertilizer application rates (Salo, Lemola and Esala, 2007) and by implementing soil-incorporating methods other than conventional autumn tillage (Rankinen *et al*., 2007). This is an example of a policy-driven means to tackle the adverse effects of climate related to agriculture and the environment.

Extreme events and other climatic constraints causing production uncertainty require continuous adaptation by farmers to cope with risks that cause economic losses. The likelihood for climatic extremes increases towards the northern regions of the Boreal Zone (Table 3). As an example, the risk of early season frost is evident everywhere in Finland, but particularly in the more northern regions. A contrary constraint to frost is represented by heatwaves occurring in May, close to sowing and seedling emergence. Such heatwaves occur at least every ten years and typically result in poor plant stand establishment. Furthermore, during the period of the most intensive growth, severe drought (<10 mm accumulated

**Table 3: Likelihood for having some exceptional weather events every 10th, 20th and 50th year, depending on region in Finland according to comprehensive modelling exercise with regional, long-term climatic datasets by Venäläinen *et al*. (2007)**

| Repeating period (years) | Helsinki (60.1 °N 24.6 °E) | | Jyväskylä (62.1 °N 25.4 °E) | | Oulu (65.0 °N 25.3 °E) | | Sodankylä (67.3 °N 26.4 °E) | |
|---|---|---|---|---|---|---|---|---|
| | 95% | 95% | 95% | 95% | 95% | 95% | 95% | 95% |
| Minimum temperature in May (°C) | | | | | | | | |
| 10 | –2.7 | –1.4 | –8.4 | –6.9 | –7.8 | –6.5 | –15.9 | –12.8 |
| 20 | –3.2 | –1.8 | –9.1 | –7.3 | –8.9 | –7.0 | –17.9 | –14.0 |
| 50 | –3.7 | –2.1 | –9.8 | –7.8 | –10.2 | –7.6 | –20.2 | –15.5 |
| **Maximum temperature in May (°C)** | | | | | | | | |
| 10 | 25.2 | 26.3 | 27.0 | 27.7 | 25.7 | 26.5 | 24.7 | 26.8 |
| 20 | 25.7 | 27.0 | 27.3 | 28.2 | 26.1 | 27.3 | 25.4 | 27.9 |
| 50 | 26.3 | 27.7 | 27.7 | 28.8 | 26.6 | 28.3 | 26.1 | 29.2 |
| **Duration of drought period in May–August with <10 mm precipitation (days)** | | | | | | | | |
| 10 | 39 | 53 | 32 | 39 | 38 | 51 | 33 | 42 |
| 20 | 44 | 68 | 35 | 44 | 42 | 64 | 37 | 51 |
| 50 | 50 | 86 | 38 | 53 | 48 | 79 | 41 | 65 |
| **Precipitation per day (mm)** | | | | | | | | |
| 10 | 47 | 66 | 46 | 64 | 38 | 54 | 35 | 45 |
| 20 | 52 | 76 | 52 | 75 | 42 | 63 | 38 | 50 |
| 50 | 60 | 92 | 61 | 92 | 50 | 77 | 42 | 57 |
| **Duration of period with daily minimum temperatures –20 °C (days)** | | | | | | | | |
| 10 | 4.9 | 7.6 | 9.2 | 13.2 | 10.9 | 13.9 | 13.0 | 18.1 |
| 20 | 6.1 | 10.4 | 10.7 | 16.5 | 11.9 | 16.0 | 14.7 | 22.9 |
| 50 | 6.9 | 15.8 | 12.3 | 21.1 | 12.9 | 18.9 | 16.9 | 28.1 |
| **Depth of snow cover at most (cm)** | | | | | | | | |
| 10 | 67 | 78 | 88 | 95 | 67 | 82 | 100 | 118 |
| 20 | 73 | 88 | 94 | 103 | 72 | 97 | 106 | 132 |
| 50 | 79 | 102 | 99 | 113 | 79 | 117 | 114 | 153 |

For each case the 95% confidence intervals are shown (the best estimate is often close to the mean of the intervals). Table is published in Peltonen-Sainio and Niemi (2012).

precipitation), lasting 35–55 days, interferes with crop growth at least once in ten years, while heavy rains (39–55 mm per day) that cause lodging and/or flooding occur once every tenth year (Peltonen-Sainio and Niemi, 2012).

As examples in the previous section indicate, farmers in the northern agricultural regions are used to facing and trying to cope with climatic constraints. This is also evident according to a recent study carried out in the northern regions of Norway (Kvalvik *et al*., 2011). However, owing to a limited capacity to cope with climatic constraints, variation in yield and quality is evident (Peltonen-Sainio and Niemi, 2012). Despite high yield variability, farmers consider that coping with agricultural policy is more challenging than coping with changing climate and climatic constraints (Kvalvik *et al*., 2011).

Climatic extremes are most hard to cope with, and can result in total crop failures. For example, during recent decades yields in 20 percent, 45 percent, 22 percent and 18 precent of the agricultural land area in Finland failed totally in 1981, 1987, 1998 and 1999 respectively (Peltonen-Sainio and Niemi, 2012). Of these years, some had exceptionally cool growing seasons, except 1999 when severe drought interfered with crop growth. Also overwintering damage may be a significant source of yield variability (Peltonen-Sainio, Jauhiainen and Hannukkala, 2007; Peltonen-Sainio, Hakala and Jauhiainen, 2011). However, in the case of total or extensive winter damage, resowing with spring crops is practised and therefore the contribution of winter damage to annual crop loss area is often masked. In general, yields of minor crops such as grain legumes and rapeseed are more vulnerable to variable conditions and climatic risks (Peltonen-Sainio and Niemi, 2012).

## 3. CLIMATE CHANGE, EXTREME EVENTS AND VULNERABILITY OF NORTHERN CROP PRODUCTION

### 3.1 Future climate forecasts: where do we go from here?

**Temperatures** are projected to rise most in northern climates and especially so in winter (December–February) and spring (March–May) when compared with other European regions (Ruosteenoja, Tuomenvirta and Jylhä, 2007). By the end of this century (2071–2100), according to the SRES A2 scenario, the probability intervals for temperature increase calculated by the GCMs range from 4.5 to 7.5 °C in winter and 2.8 to 7.2 °C in spring months when compared with the 1961–1990 period. The corresponding figures for the SRES B1 scenario are 2.5 to 5.4 °C and 1.4 to 5.0 °C, respectively. These estimates are in general some 0.5 to 2.0 °C higher than for western, southwestern and southeastern Europe, though closer to those calculated for eastern Europe. Contrary to this, the probability intervals for temperature elevation during summer months (June–August) are substantially lower for northern regions than for elsewhere: 2.0 to 5.4 °C for A2 and 1.0 to 3.8 °C for B1, while being even 2.6 to 8.4 °C for A2 and 1.6 to 5.3 °C in eastern Europe (Ruosteenoja, Tuomenvirta and Jylhä, 2007). Intervals for temperature changes were most alike for autumn months (September–November) in European regions with a ≤1.0 °C difference at most for the A2 scenario and even less for B1. Therefore, in the north winters are expected to get milder and the growing seasons to become warmer and prolonged, by 40–50 days in inland areas of Finland and even more in the southwestern coastal regions of the country (Ruosteenoja, Räisänen and Pirinen, 2011).

**Precipitation**. In Europe, projections for precipitation differ depending on season, and within a season depending on region (Ruosteenoja, Tuomenvirta and Jylhä, 2007). For winter months, the highest increase in precipitation is projected by GCMs to take place in northern European regions by the end of the century when compared with 1971–1990 (up to 50 percent in A2 and ~30 percent in B1 scenario). However, uncertainty due to the choice of GCM is particularly high for winters, especially for northern climates (Kjellström and Ruosteenoja, 2007). For southwestern and southeastern climates, winter precipitation may increase or fall by about 20 percent at most. For spring months, the probability intervals for northern climates are comparable with estimates for eastern regions and range from no change up to ~40 percent and a 20 percent increase in precipitation according to A2 and B1 scenarios, respectively. For southwestern and southeastern regions, change in spring precipitation is likely to be negative. In general, autumn precipitation is estimated to change according to spring precipitation but the probability intervals will narrow.

Northern Europe represents the only region for which probability intervals for summer precipitation are projected to slightly increase (ranging from ~0 percent to 15 percent regardless of forcing scenario). Elsewhere in Europe summers are projected to get drier (Ruosteenoja, Tuomenvirta and Jylhä, 2007). For example, in Finland summer precipitation is estimated to gradually increase by the end of this century with regard to both the multi-model-mean precipitation and the variation (Ylhäisi *et al*., 2010). Therefore, precipitation is projected to increase in northern European climates throughout the year with differences in seasonal distribution: winters will get wetter, as is also the case, but to a lesser extent, for spring and autumn, than for winters, and again a little less increase in precipitation for summer than for spring and autumn. Also within the growing season precipitation is projected to increase unevenly, the absolute increase estimated to be largest in July (Ylhäisi *et al.,* 2010).

**Winter conditions**. As a result of higher estimates for future winter temperature and precipitation, major changes are projected to take place in winter conditions, such as fewer days with frost and snow, shorter frost season and a smaller liquid water equivalent of snow (Jylhä *et al.,* 2008). These projected changes were produced by all model simulations irrespective of the forcing scenario and the driving GCM, and they evidently have implications for agriculture based on "the mercies of nature". Annual number of frost days is predicted to decline from an average of ~120–180 days in the main agricultural regions of the Boreal Zone by 50–70 days by the end of this century according to the A2 forcing scenario (Jylhä *et al*., 2008). Also the number of freezing point days will decline in autumn by 5–10 days and in spring by 10–15 days in the southernmost regions of the Boreal Zone and by 0–5 days in the northernmost regions. Contrary to this, freezing point days will become more frequent in winter months and especially so in the northern parts of the Boreal Zone.

As a result of climate warming the first frost day in autumn will be delayed by about one month and the last frost day in spring advanced by one month by the end of the century (Jylhä *et al*., 2008). The number of days with snow cover over land areas ranges from ~90 to 200 (1961–1990) at the south-north axis in the Boreal Zone, but declines by 30 to 60 days, with the most drastic change occurring in the southern regions. The annual extent of snow cover at high latitudes has already declined in recent decades (Zhang and Walsh, 2006). Decline in days with snow cover is estimated to be most prominent during spring months (Jylhä *et al*., 2008). In general, under the A2 scenario, thermal winters may disappear in southwestern Finland by the end of the century (Ruosteenoja, Räisänen and Pirinen, 2011).

An indication of severity of winter conditions is represented in northern European regions by the extent of Baltic Sea ice. By the end of this century, unprecedentedly mild and extremely mild winter conditions will dominate regardless of the model used for projections (Jylhä *et al.,* 2008). Thereby, all the different weather parameters that characterize winter conditions and that are likely to have evident impacts on overwintering capacity of field crops and expression of winter damage in established plant stands will change in tandem. This challenges anticipation and adaptation of northern cropping systems to changing climate, especially concerning expansion of overwintering crop areas (Peltonen-Sainio, Hakala and Jauhiainen, 2011).

**Extreme events** are, in general, expected to become more frequent in the future when climate changes. There is evidence from observations gathered since 1950 of change in some climate extremes. Also economic losses from weather-related and climate-related disasters have increased though, with large spatial and interannual variability (IPCC, 2012). Heatwaves, episodes of heavy precipitation and/or severe drought, wind storms and storm surges are projected to change in Europe between 1961–1990 and 2071–2100 according to RCM simulations (Beniston *et al.,* 2007). In northern Europe, frequency, number and intensity, and duration of heatwaves will increase (shown in order from the highest to the lowest change). When the mean annual number of days exceeding 30 °C was 0–5 for the period 1961–1990, for the end of this century in the southernmost regions of the Boreal Zone, such episodes are likely to become more common and may range from five to ten by the end of this century (Beniston *et al.,* 2007). In southern Europe days with >30 °C may then approach 100.

Episodes of heavy winter precipitation are estimated to increase in both northern and central Europe as well as heavy summer precipitation events in northeastern Europe, but both winter and summer precipitation episodes will become more rare in the south (Beniston *et al.,* 2007). For example, at high latitudes (62.5 °N) the number of months in which the highest monthly precipitation is simulated to break the records of the twentieth century is ten by the end of this century in A1B scenario (six in the case of unchanged climate), though the estimate is four months for the Balkan Peninsula (42.5°N) (Ruokolainen and Räisänen, 2009). The corresponding estimates for the number of months with the highest mean temperature are 11 (for 62.5 °N; six in unchanged climate) and 12 (for 42.5 °N), respectively. Furthermore, in Finland the high precipitation records are more likely to be broken than the low precipitation records (Ruokolainen and Räisänen, 2009). Projected changes in precipitation and temperature imply possible changes in flooding patterns (IPCC, 2012).

**Shift in environmental zones**. Climate change is projected to result in changes of many critical agro-climatic indices (Table 1, Trnka *et al.,* 2011). Eventually also climate subtype distributions may change in such a manner that the subarctic continental climate will disappear northwards beyond the present agricultural land by the end of this century (de Castro *et al.,* 2007). On the other hand, the temperate continental climate will start to dominate in the high latitude countries of Europe and a temperate oceanic climate may reach some of the southern and southwestern coastal parts of Sweden and Norway.

## 3.2 Impacts of climate change and vulnerability of agro-ecosystems

**Prolongation of growing season**. The current, extremely short growing season of northern European agricultural regions is projected to become longer in the future. This is likely to occur by benefitting from the advanced start to spring sowing, but not necessarily from delayed maturity and harvest in autumn. Advances in sowing time are estimated to proceed rapidly at latitudes >60 °N (Peltonen-Sainio *et al.,* 2009a; Rötter *et al.,* 2011). Elevated daily mean temperatures during the growing season partly chip away at the crops' capacity to benefit from climate-warming induced higher cumulated degree-days during the growing season. Higher degree day values in the future will be attributable to both elevated daily mean temperatures and greater number of days in the early and late growing season with daily mean temperatures exceeding +5 °C. However, elevated temperatures are harmful for growth and yield determination for a variety of grain and seed crops, as described in more detail below, and call for adaptation through plant breeding (Peltonen-Sainio *et al.,* 2009a; Rötter *et al.,* 2011; Hakala *et al.,* 2012). Growing season accumulated temperature sums that are estimated to be utilized by crops for growth and are agronomically feasible (means earlier sowings, but not delays in harvest period) were anticipated to increase by some 140 °Cd by 2025, 300 °Cd by 2055 and 470 °Cd by 2085 in scenario A2, when averaged over regions with significant arable land in Finland (Peltonen-Sainio *et al.,* 2009a). Thereby, the extent of potential cultivated areas for many crop species is anticipated to expand at high latitudes in Europe.

**Improvements in potential for crop diversification**. Potential cultivated areas of the commonly grown major and/or minor crops (depending on Boreal region) will increase considerably, especially above their current northern limits for cultivation (Peltonen-Sainio *et al.,* 2009a). By the mid-century some of the contemporary crops, spring cereals, rapeseed and grain legumes will be grown up to 65–66 °N, i.e. as far north as there is arable land available in the Boreal Zone. Already this opens new opportunities for diversified crop rotations (Peltonen-Sainio and Niemi, 2012). Of the current spring-sown minor crops, oilseed rape, pea and faba bean (*Vicia faba* L.) are particularly strong candidates to become major crops in northern European regions. These crops have good potential for industrial processing, they are currently being bred and there is substantial need to substitute imported soybean (*Glycine max* L.) with regionally produced protein crops (Peltonen-Sainio and Niemi, 2012; Peltonen-Sainio *et al.,* 2012).

In addition to opening doors for expansion of areas for present crops, novel or extremely marginal minor crops may be introduced. Owing to the higher base temperature requirement for maize (*Zea mays* L.) growth than for temperate crops, silage maize could become a novel crop for the most favourable growing regions of the Boreal Zone, up to 61–62 °N by the end of this century (Peltonen-Sainio *et al.,* 2009a). Grain maize would only like gain ground across southernmost regions of Sweden (Elsgaard *et al.,* 2012) owing to the requirement for a long growing season and its being frost and chilling sensitive. When bench-marking the current cropping situation in a nearby region, grain maize has in fact only recently been introduced into Denmark due to elevated temperatures during the growing season, while forage maize has been an important crop there for a long time (Olesen *et al.,* 2011). Cultivation of current minor crops that require 1000–1100 °Cd and/or are prone to frost, e.g. buckwheat (*Fagopyrum esculentum* Mill.), flax (*Linum usitatissimum* L.), oil hemp (*Cannabis sativa* L.) and sunflower (*Helianthus annuus* L.), is today limited up to 62 °N and/or only in the most temperature-favoured regions, but their cultivation could expand northwards or increase in the present regions (Peltonen-Sainio *et al.,* 2009a).

As winters become milder, the temperature regimes in the northern regions of the Boreal Zone may gradually start to resemble those typical of southern Sweden and Denmark today. It is possible that expansion of winter-sown crops (cereals and rapeseed) northwards will represent major risks as a result of fluctuating winter conditions, and this could delay their adaptation for expanded production by many decades. Winter wheat (*Triticum aestivum* L.) and triticale (X *Triticosecale* Wittmack) may have the potential for expansion in the first wave, turnip rape thereafter, and winter barley and oat (*Avena sativa* L.) much later (Peltonen-Sainio *et al.,* 2009a). Also potential for introduction of new or neglected perennial grasses and forage legumes or expansion in their production in current regions may be improved along with prolonged, warmer growing seasons with milder winters (Hakala *et al.,* 2011).

**Elevated temperatures** are harmful to cereal and rapeseed yields throughout Europe (Reidsma and Ewert, 2008; Peltonen-Sainio *et al.,* 2010), and this sensitivity is also expressed in the northernmost European regions (Peltonen-Sainio *et al.*, 2010; Peltonen-Sainio, Jauhiainen and Hakala, 2011; Kristensen, Schelde and Olesen, 2011). According to numerous studies carried out in many cropping regions across the globe, it seems evident that the present cultivars are adapted to rather narrow ranges of temperature typical for northern European growing seasons (relatively cool conditions at high latitudes) and even a small and temporary increase in mean and/or maximum temperatures reduces yields.

Heatwaves – elevated temperatures of extended duration – are particularly harmful for crop production under northern conditions as together with long days they accelerate developmental rate if they occur prior to heading or at flowering (for seed producing crops), or they cause premature maturation when occurring at grain-filling (Peltonen-Sainio, Jauhiainen and Hakala, 2011; Hakala *et al.,* 2012). For example, rapeseed is particularly sensitive to elevated temperatures at late seed set and during seed fill: years with elevated temperatures often coincided the years with greatest yield losses (Peltonen-Sainio, Jauhiainen and Hannukkala, 2007). Also Frenck *et al.* (2011) showed that elevated temperatures were particularly harmful for yield formation of oilseed rape cultivars, though not their biomass. Episodes of elevated temperatures are often associated with drought, causing more severe yield reductions (Rötter *et al.,* 2011) and challenges for regrowth of cut grass crops. As an example of the impacts of elevated temperatures at national level, Peltonen-Sainio, Jauhiainen and Hannukkala (2007) found that higher temperatures accounted for up to two-thirds of the recorded, marked yield declines in rapeseed in Finland. Temperature elevation may cause yield losses also for winter cereals (Peltonen-Sainio, Jauhiainen and Hakala, 2011), as grain yield of winter wheat responded non-linearly to mean winter temperatures, with the highest yield at 4.4 °C and lower yields both below and above this inflection point (Kristensen, Schelde and Olesen, 2011). Peltonen-Sainio, Jauhiainen and Hakala (2011) did, however, show that elevated temperatures during the growing season were not harmful for winter wheat or rye (*Secale cereale* L.).

The negative effects of +5 °C elevation on yields cannot be compensated for by elevated $CO_2$ concentration (770 ppm) (Frenck *et al.,* 2011). Also the experiments of Hakala (1998) showed that the benefits for growth provided by $CO_2$ enrichment (700 ppm) for spring wheat tended to compensate partly, but not completely, for the yield losses caused by elevated temperatures (by 3 °C). This was also evident according to a model-based assessment (Rötter *et al.,* 2011), according to which total growth duration decreased and yield losses were apparent at temperature increases exceeding 3 °C. Another exercise used long-term datasets of field crops typical for Finland and compared crop responses with elevated temperatures through grouping experiments according to the temperature range experienced during the growing season. Yield losses were again apparent for years having typical temperatures estimated for 2025 when compared with those typical for 1985 (Peltonen-Sainio, Jauhiainen and Hakala, 2011).

**Increases in precipitation**. In general, anticipated increases in early summer precipitation would have favourable impacts on crop production, while the projected increase in precipitation in August and September anticipates harmful impacts on crop maturation, harvest and quality (Ylhäisi *et al.,* 2010). Over recent decades, early summer drought has already somewhat eased off in the Boreal Zone, for example in the southwestern regions of Finland, as 5–9 mm more June precipitation was recorded per decade (Ylhäisi *et al.,* 2010). This is likely associated with 140–230 kg/ha higher grain yields in spring cereals and may, thereby contribute 15–20 percent of the cereal mean yield increases, recorded to be 1000–1600 kg/ha during the period from the 1960s to the 2000s (Peltonen-Sainio, Jauhiainen and Laurila, 2009). Such impact on yields results from increases in precipitation at the most critical developmental phase for yield formation of many seed producing crops. However, in the future more dramatic increases in precipitation are likely needed in order to meet the demands of more abundant plant stands supporting improved yield potentials, and to avoid that plant stands suffer from insufficient access to water when temperatures rise in the northern long day conditions (Ylhäisi *et al.,* 2010). If rain showers become more abundant and irregular in the future (as one manifestation of more general extreme events), rains become less efficiently used by crop stands and distribution of precipitation may meet the demands of the crop stands less efficiently. On the other hand, excess rain causes lodging, delayed ripening of plant stands, flooding with anoxia and results in deterioration of quality.

**Milder winters**. Typically temporal and spatial inter- and intra-annual variation in overwintering damage is high under northern growing conditions, exhibiting drastic regional differences in winter conditions in a south–north dimension. It is likely that in the near future climatic constraints are likely to become too harsh for successful expansion of overwintering crops because the winters may combine mild and severe periods, and fluctuation in winter conditions *per se* challenges overwintering capacity (Hakala *et al.,* 2011; Peltonen-Sainio, Hakala and Jauhiainen, 2011). Fluctuating conditions for winter wheat in particular have typically hampered overwintering, and freezing point days are likely to become more frequent in winter months and especially so in the northern parts of the Boreal Zone (Jylhä *et al.,* 2008). On the other hand, in the future further increasing autumn precipitation challenges winter rye that has presently better overwintering capacity than winter wheat (Peltonen-Sainio, Hakala and Jauhiainen, 2011), while low winter temperatures that have been critical for overwintering success of winter rye are projected to ease off.

**Emerging crop protection risks**. In general, and concerning the vast majority of cases, the changes in climatic conditions described above are likely to increase risks related to weed, pest and pathogen infestations in the future (Hakala *et al.,* 2011). The impacts of changes in severity of risks and predispositions of crops are not, however, straightforward due to the complex nature of interactions between climatic conditions (microclimates in crop stands), crop performance, incidence of pests and their predators, pathogens and their antagonists, weeds and their competitors, appearance of host plants other than cultivated crops, viruses and their vectors, etc. Another dimension of emerging crop protection risks in the future is introduction of alien species into northern agro-ecosystems (Hyvönen and Jalli, 2011; Vänninen *et al.,* 2011; Hannukkala, 2011). All these issues emphasize the need for region-dependent assessments of crop protection risks on a case-by-case basis.

## 4. NEEDS AND MEANS FOR ADAPTATION AT THE NORTHERN MARGIN OF AGRICULTURE

Adaptation is the key factor that will shape the future severity of climate change impacts on food production (Lobell *et al.,* 2008). Adaptation can largely reduce the potential harmful impacts of climate change and thereby alleviate variability of crop yields and farmer income (Reidsma *et al.,* 2010). In northern growing conditions, prompt adaptation measures are needed as changes in conditions are projected to be considerable and warming will proceed rapidly. On the other hand, owing to the lag period even after successful, globally followed-through mitigation measures, climate change will shape future agriculture at high latitudes.

As the examples above (section 2.2) indicate, farmers in northern areas are accustomed to adapting to continuously varying conditions. However, foreseen profound changes in regional production capacities and cropping patterns in the northern European conditions call for changes in agricultural policy. Need for policy guidance is particularly emphasized if highly productive fields are going to be sustainably intensified in the future, while poor performing extensified. One can characterize the present common agricultural policy (CAP), LFA and national payments as being rather inflexible. They are about to sustain existing production structures and means without necessarily encouraging towards the radical changes that are essentially required for successful adaptation as described below (sections 4.1 and 4.2). Ideally policy incentives should encourage and reward coupling of improvements in realization of production capacities (i.e., catching up emerging yield gaps; Peltonen-Sainio, Jauhiainen and Laurila, 2009) with environmental benefits and orientation according to market demands. This also means motivating investments for consolidating production and competitiveness as well as improving environmental care when adapting to climate change. Successful adaptation as such is a means to increase resilience of northern crop production, but hedging against yield losses and failures caused by climate variation and extreme events may imply development of, for example, weather index insurance systems (Myyrä, Pietola and Jauhiainen, 2001; Pietola *et al.,* 2011).

Climatic extremes will have significant impacts on agriculture and food security (IPCC, 2012). Developed countries are, in general, better equipped financially and institutionally to adopt specific measures to respond and adapt to projected changes efficiently regarding exposure and vulnerability to climate extremes (IPCC, 2012). In general, reducing exposure, increasing resilience to changing risks and reducing vulnerability of cropping systems are the key management approaches to adapting to a changing climate (IPCC, 2012).

## 4.1 Aiming at redeeming prospected opportunities

In general, prolonged growing seasons and an elevation in $CO_2$ concentration would increase yield potentials of major field crops. Estimates for increases in yield potentials are substantial, and suggest even doubling of yields per hectare (Peltonen-Sainio *et al.,* 2009a; Olesen *et al.,* 2011), but their realization in future climates requires many adaptation measures. Benefits in yield potential are gained indirectly if lower-yielding crops are replaced by more productive ones.

Field use in northern Europe may change drastically in the future. There is potential to markedly diversify cropping systems. Cultivation of crops that benefit relatively more from prolonged growing seasons, and are thereby more competitive, may be expanded most if their production uncertainties are managed. As an example, in the near future oilseed rape is likely to replace low-yielding turnip rape, a globally marginal crop that is currently grown and bred within Europe only in Finland (Peltonen-Sainio, Jauhiainen and Venäläinen, 2009; Peltonen-Sainio *et al.,* 2009a, 2009d). This is an example of adaptation means to better utilize the future conditions through enhancing yield potential. The role of other protein crops, faba bean, pea and lupins (*Lupinus* spp.) to substitute partly for imported soymeal may also increase owing to high demands for protein-rich feed sources in the future and when there are better opportunities to produce such crops in northern regions. Also the prospects for expanded production of high-yielding triticale are good as only modest increases in winter temperature enable its production at larger scales than are possible today. It may expand at the expense of spring fodder cereals, barley and oat. Also other overwintering types of presently dominant spring sown cereals, especially wheat, may become more common also in the northernmost regions of the Boreal Zone (Peltonen-Sainio *et al.,* 2009a). Also novel crops such as maize may eventually approach the northern agricultural regions (Peltonen-Sainio *et al.,* 2009a; Elsgaard *et al.,* 2012) though prospects for soybean production remain poor. In fact, farmers in Finland started to gather experience in cultivation of forage and bioenergy maize in the 2000s when heartened by warm summers. Introducing grain legumes, peas and faba bean in particular into crop rotations offers many ecosystem services that directly or indirectly contribute to improved resilience to climate change (Peltonen-Sainio and Niemi, 2012).

The growing season in northern Europe became two to three weeks longer during 1890–1997, and the prolongation took place both at the beginning and at the end of the growing season (Carter, 1998). Since 1965, the thermal growing season has in general started 2.0–2.8 days earlier per decade in Finland, except in the 1980s (Kaukoranta and Hakala, 2008) when a couple of exceptionally cool growing seasons occurred (Peltonen-Sainio and Niemi, 2012). Farmers have already adapted by sowing spring cereals 0.6 to 1.7 days earlier, depending on the region, while sugar beet and potato were sown 2.5 and 3.4 days earlier respectively (Kaukoranta and Hakala, 2008). In the case of potato, technology changes also enabled earlier sowing despite the acute sensitivity of potato to damage from night frosts.

This is an indication of an already occurring adaptation to climate warming and expansion of growing season in northern conditions.

## 4.2 Coping with challenges

Improvements in the resilience of northern cropping systems require that wide-ranging adaptation measures to changing and fluctuating conditions are taken. Realizing the prospects for increased yield potentials in northern regions, enabling marked diversification in cropping systems and improving resilience of northern crop production require adaptation measures (Table 4). In the future farmers will need to cope with: (i) elevated daily mean temperatures that interfere with crop growth, particularly when occurring under the long day conditions of northern latitudes; (ii) scarcity of water at critical phases of yield determination and harmful effects of abundant precipitation late in the growing season; (iii) greater pest, disease and weed pressure under future climates and cropping systems; (iv) other uncertainties caused in particular by extreme events; and (v) a generally greater need for inputs, especially nitrogen and crop protection agents and measures (Peltonen-Sainio *et al.*, 2009a).

**Breeding for high temperature insensitivity or escape**. Only plant breeding can provide comprehensive, primary solutions and thereby adaptation means to counter the negative impacts of elevated temperatures in the northern regions (Peltonen-Sainio *et al.*, 2009a; Peltonen-Sainio, Jauhiainen and Hakala, 2011; Rötter *et al.*, 2011). A recent study indicated that modern rapeseed cultivars were especially sensitive to elevated

**Table 4: Main climate change adaptation needs and means to improve production capacity and resilience of northern crop production**

| Constraint | Crops of particular concern | Adaptation measure(s) needed |
|---|---|---|
| Long days, elevated temperatures, enhanced development rate | Seed crop plants | Breeding for insensitivity to elevated temperatures |
| Water availability and distribution | Spring sown crops | Development of year-round water management systems (including irrigation), breeding for improved water use efficiency, expanding cultivation of winter crops that have ability to escape early summer drought |
| Winter hardiness | Overwintering crops | Breeding for improved overwintering capacity, avoiding introduction of cultivars not well adapted to northern climates |
| Crop protection risks | All crops | Healthy propagating material, breeding for disease resistance, chemical and biological control systems, alarm systems |
| Extreme events | All crops | Alarm systems, breeding for improved yield stability, improving resilience through crop diversity |
| Access to nutrients | All crops | Fertilization practices (including split fertilizer use), crop rotations, increased cultivation of nitrogen-fixing legumes, breeding for improved nitrogen and phosphorus use efficiency |

*Source*: Peltonen-Sainio *et al*. (2009a).

temperatures experienced in northern European conditions (Peltonen-Sainio, Jauhiainen and Hannukkala, 2007). It is possible that with climate warming, breeding lines will be more frequently exposed to elevated temperatures already during the selection programmes, and thereby responsiveness to elevated temperatures will to some extent be spontaneously addressed. However, as climate warming is likely to progress gradually, it means that newly released cultivars will always be better adapted to past rather than future temperature conditions, as might be the case with rapeseed temperature sensitivity recorded for Finnish conditions (Peltonen-Sainio, Jauhiainen and Hannukkala, 2007). Therefore, owing to the long time period needed in breeding new cultivars, prompt actions are called for, together with strategies (Table 4) that have clear sense of direction to counter the harmful and more aggravated impacts of heat in the future (Ortiz *et al.,* 2008).

Adaptation through altering cropping patterns can, in certain cases, ease the exposure of plant stands to the most critical temperature elevations. For example, introducing winter types that benefit from or are less susceptible to elevated temperatures (Kristensen, Schelde and Olesen, 2011; Peltonen-Sainio, Jauhiainen and Hakala, 2011) is a means to adapt to elevated temperatures. In the future, for example, replacing the most early maturing fodder barley with fodder triticale or introducing later maturing barley cultivars may be among the means to avoid or escape the evident risk of yield losses. Also changes in sowing time may be a means of avoiding critical growth phases that occur during times of stress, though for northern conditions the range of shift in sowing time is very limited and applicable only for the fastest maturing cultivars. However, according to a model-based assessment, adjustment of sowing time in spring barley did not alleviate yield losses sufficiently (Rötter *et al.,* 2011). For winter wheat, avoiding harmful temperature effects is also possible through delayed sowing or by growing cultivars with a higher vernalization requirement and/or stronger day length requirement (Kristensen, Schelde and Olesen, 2011).

In addition to shifting time of major phenological events, for example by earlier sowing (Olesen *et al.,* 2012), another means to adapt to changing temperature conditions is through shifting the duration and timing of phenological phases via plant breeding. For example, Patil *et al.* (2010a) suggested that winter wheat would be better adapted to the expected warmer winters if genotypes had a longer vegetative period, without advancing their reproductive stages. By such means, yield levels could be maintained even under shorter growing seasons. Another example of a trade-off between major developmental phases that has occurred in spring oat in Finland is that modern, higher-yielding oat cultivars have a shorter period from sowing to harvest compared with older cultivars owing to their shorter grain-filling period and higher share of the pre-anthesis period compared with the duration of the post-anthesis period (Peltonen-Sainio and Rajala , 2007). This has likely increased yield stability of oat by reducing risks related to delayed harvests. These examples emphasize the potential for trade-offs between developmental phases in order to adapt to changing temperature conditions. And in addition to temperature change, induced shifts in phasing may be a means to escape drought or risks of night frosts.

**Developing water management systems**. Despite the ability to moderate negative impacts of climate change through rather inexpensive changes in cropping systems, the largest benefits are likely to result from costly water management measures, including irrigation (Lobell *et al.,* 2008). Finland has exceptionally abundant, good-quality freshwater resources, but currently they are utilized for irrigation only in horticulture, and thus the total irrigated area remains small. The present and future major constraint of limited water can be solved through irrigation, but this requires developing systems that not only focus on enhancing productivity through irrigation but also protect the environment. The environmental load from agriculture is, in general, expected to increase in northern European aquatic environments (Jeppesen *et al.,* 2011). On the other hand, projected increases in precipitation outside the growing season challenge overwintering and soil drainage and represent a higher risk for nutrient loads, erosion, poor soil bearing capacity and soil compaction. Therefore, water resource management faces great challenges throughout the year. All these call for adaptation measures that include development of comprehensive water management systems (Table 4). Also, means other than irrigation may improve resilience of cropping systems with respect to water scarcity at critical developmental phases. For example, soil water-holding capacity may be improved in the long run by water conservation methods such as adding crop residues and manure to soils (Smith and Olesen, 2010) and using reduced tillage or direct drilling (Känkänen *et al.,* 2011).

**Sustaining expansion of overwintering crops**. Milder winters in the future may open up new opportunities for introduction of autumn-sown overwintering crops in the Boreal Zone to a greater extent than they are cultivated today (Peltonen-Sainio *et al.,* 2009a). For example, Finland is among the most virgin temperate areas for winter types of grain and seed crops, as the only currently grown crops, winter rye and wheat, cover only 1 percent of agricultural land. Winter types are attractive because of their higher yield potential, better ability to avoid early summer drought-induced yield losses, and soil cover, reducing risk of erosion and nutrient leaching. According to Patil *et al.* (2010b), projected future increases in drainage and nitrogen leaching are offset by increased water and nitrogen removal by the advanced growth of crops driven by warmer winters. It is, however, likely that, in the near future, climatic constraints are likely to be too harsh for successful overwintering of crops as winter may comprise mild and severe periods and the expected fluctuation in winter conditions will challenge the overwintering capacity of crops (Peltonen-Sainio, Hakala and Jauhiainen, 2011). Therefore, cultivation of winter crops may experience massive expansion by the mid-century (Table 5), as by then winters are likely to be “permanently” milder. An example of farmers’ continuous adaptation in northern conditions is that severity of winter damage in any one year is associated with a smaller area sown in the following year (Peltonen-Sainio, Hakala and Jauhiainen, 2011).

Contrary to the current situation in the northernmost Boreal region, Finland, in Uppland in Sweden, which lies at a comparable latitude to southernmost Finland, winter types of rapeseed have already been successfully adapted for cultivation. For example, in 2008 there were only 1300 hectares of spring turnip rape in Sweden and the crop seemed set to vanish from cultivation in the near future. Under future Finnish conditions, spring turnip rape will probably remain an important crop only in the northernmost growing regions, and it is likely to play an important role as a pioneer crop when new regions are approached. It seems likely that in northern regions as a whole, not only oilseed rape will dominate as an oil crop in the future, but also winter types will gradually approach the northernmost cropping regions of the Boreal Zone (Peltonen-Sainio *et al.,* 2009a).

**Providing for increasing pest, disease and weed problems**. Agriculture in the Boreal Zone has been favoured by exiguous risks represented by pests and diseases, when compared with the more southern regions of the northern hemisphere. However, changing climatic conditions and the means to adapt to these through changes in cropping patterns and systems may initiate new problems with higher occurrences of weeds, pests and pathogens (Hakala *et al.,* 2011). Major drivers for more challenging crop protection risks in the future are various. Among some examples are introduction of new species favouring prolonged growing seasons and elevated temperatures, expansion of cultivation of winter crops, stresses caused to crops by climatic constraints and increased sensitivity of crops to pest, disease and weed infestations, and a greater number of generations of pests reproduced in a prolonged and warmer growing season (Hakala *et al.*, 2011). Another dimension of further emerging crop protection risks in the future is introduction of alien species into northern agro-ecosystems (Hyvönen and Jalli, 2011; Vänninen *et al.,* 2011; Hannukkala, 2011).

The prospected changes in northern growing conditions call for adaptation measures such as resistance breeding, development of alarm systems, increase in frequencies of control treatments, and introduction of biocontrol opportunities, in addition to chemical control, production of healthy propagation material and increased use of high quality, upgraded or commercial certified seed (instead of farm-saved seed, which is the major current practice, Peltonen-Sainio, Rajala and Jauhiainen, 2011). There has also to be consciousness of potentially associated changes in vulnerability of developed management practices and cropping systems to crop protection risks. Owing to the complex nature of interactions between various factors affecting the success of pest, pathogen and weed infestations in the future (see above) region-dependent, case-by-case assessments of the means to cope with crop protection risks are needed even within the Boreal Zone.

### 4.3 Match or mismatch of adaptation and mitigation?

Agriculture needs to both reduce greenhouse gas emissions and adapt to a changing and more variable climate, but there is likely potential for synergies between adaptation and mitigation (Smith and Olesen, 2010). Adaptation and mitigation cannot be considered as separate routes to progress and virtually all the mitigation measures have direct or indirect impacts on the carbon and/or nitrogen cycle of agro-ecosystems (Smith and Olesen, 2010). In general, adaptation measures also have positive effects on mitigation, especially concerning measures that reduce soil erosion, increase nutrient use efficiency, reduce nitrogen and phosphorus leaching, conserve soil moisture, increase crop diversity, modify microclimate to reduce temperature extremes, sustain extensification of low productivity fields and avoid clearance of new fields (Smith and Olesen, 2010). However, especially on the dairy farms of the northern parts of Finland, new fields with peat soil (which due to their high carbon content are especially prone to high greenhouse gas emissions when incorporated) have been cleared, not for increased crop production *per se*, but to provide an expanded field area where manure can be applied to avoid excess nutrient loads per hectare.

The question of match or mismatch of adaptation and mitigation is even more relevant in northern Europe owing to the high climatic risks for agricultural production, variable weather conditions during growing seasons and even crop failures caused by extreme climatic events (Peltonen-Sainio and Niemi, 2012). In general, success in adaptation to climate change, i.e. implementing practices, cropping patterns and systems for climate-smart agriculture, not only improves resilience of northern agro-ecosystems, but through higher yielding capacities of crops strengthens the carbon sink at the regional level, though not in the context of contributing to global carbon sequestration or being anyhow comparable to the sink represented by Boreal forests. Nevertheless, in the case of insufficient adaptation, the environmental (also carbon) footprint of northern crop production is likely getting bigger, as vulnerability to climatic constraints in the future may result in yield losses and variability, which again will be associated with insufficient nutrient uptake, reduced nutrient use efficiencies and energy inefficiency, and farmers will hold back other essential management measures because of cautiousness regarding economic risks, etc.

## 5. TOWARDS RESILIENT CROPPING SYSTEMS WITH IMPROVED ADAPTIVE CAPACITY

Field crop production is universally susceptible to fluctuating weather conditions, irrespective of crop and environment. Though the global food supply is complex in nature, Lobell and Field (2007) showed that simple indicators of growing season temperatures and precipitation explained 30 percent or more of year-to-year variations in global average yields for the six most grown crops. Even though major advances have taken place, when it comes to development of cropping systems, technologies and breeding for phenotypic stability, management of climate-induced fluctuations in yields is often inefficient. It has been amply demonstrated that extreme and/or untimely critical weather events, especially drought, flood, heat and cold, cause major damage to food production systems, resulting in crop losses, and sometimes total failures over vast areas (Kumar *et al.,* 2004; Sivakumar, Das and Brunini, 2005; Battisti and Naylor, 2009). In the future, extreme events are projected to become more frequent as the climate changes (Klein Tank and Können, 2003; Alexander *et al.,* 2006; IPCC, 2007; Battisti and Naylor, 2009). Northern European agriculture is not projected to be in any way immune to such challenges today or in the future.

An essential step to improve resilience of northern cropping systems to changing climates is to develop the necessary activities for implementation of recognized adaptation strategies. They are essential to reduce vulnerability of northern crop production in the future (Table 4). As a part of this process, the National Adaptation Strategy (NAS) was launched in Finland in 2005 as the first NAS in Europe, followed by many others over several successive years (Biesbroek *et al.,* 2010). Strong interaction and dialogue among stakeholders, policy-makers, farmers, extension services, researchers, etc. are needed to implement the challenging list of adaptation requirements within a relatively short

**Table 5: Example of anticipated time frames for specific significant changes in Finnish arable crop production required by climate change adaptation and implemented in order to improve resilience of northern cropping systems**

| Time frame | Anticipated change |
|---|---|
| 2015→ | Increased need for crop protection and more diverse control options: anticipation and control increasingly important to avoid production risks and volatility in yields. |
| 2015–2025 | Current cultivars give way: new range of cultivars move gradually from southernmost towards northern regions of Boreal Zone. Yield potentials increase, as do also realized yields in case of successful adaptation measures. |
| 2015–2025 | Cropping systems are diversified: for example, oilseed rape has replaced turnip rape also in the northern European cropping systems and grain legumes are cultivated more commonly to improve crop-based protein self-sufficiency and benefit from many of the ecosystem services (including nitrogen) that diversified cropping systems provide. |
| 2020–2040 | Crop production is sustainably intensified and thereby concentrated in the most favourable production regions in Boreal countries: excess arable land is used e.g. for production of commodity exports, bioenergy production, strongly specialized production and/or as naturally managed fields. |
| 2020–2040 | Water management systems for northern agro-ecosystems have been developed and implemented, especially into sustainably intensified production regions of the Boreal Zone. Thereby, nutrient cycles are more "closed". |
| 2055→ | Spring sown crops are largely replaced by winter types and cultivars. This concerns many cereals and rapeseed in particular. |
| 21st century | Extreme weather events cause a great deal of uncertainty for production: spatial and temporal success in production is accompanied with failures elsewhere. Adaptation needs to become more and more appreciated as a means to improve resilience of northern agro-ecosystems. |

time frame. An example of the requisite time frame for getting results from successful implementation of adaptation measures, in order to improve resilience of northern cropping systems, is shown in Table 5.

Successful implementation of adaptation measures together with climate change-induced opportunities for gaining higher yields in prolonged northern growing seasons are the main drivers for considering future field use alternatives. Namely, increases in future yield potentials may be so significant (Peltonen-Sainio *et al*., 2009a) that presently available arable land proves to be excessive. Moreover, as production capacities of fields range from highly productive to poor, and parts of them are surrounded or plugged into highly vulnerable environments, seeking for a balance between sustainable intensification and extensification of cropping systems is justified as a future task. Extensified fields with low or hardly any input use may serve as nature preserving areas that also contribute to biodiversity enrichment. On the other hand, presently underperforming fields allowing more efficient agricultural production should be those sustainably intensified in the future decades (Table 5). It is obvious that there are likely to be large regional differences between needs for extensification and sustainable intensification of cropping systems. However, also within each farm there are fields that earn intensification as well as those better to extensify. Sustainable intensification concerns food production in particular, as is also the case with field-produced bioenergy if not otherwise competitive (e.g., sufficient production volumes, well-functioning logistics) and having a sufficiently low environmental footprint.

## 5.1 Contribution of breeding to more resilient cropping systems

Europe is among the world's largest and most productive suppliers of field products (Olesen and Bindi, 2002). In general, in each country, and often in different regions within a country, various crops are grown that are considered to be sufficiently adapted to the prevailing conditions. This is particularly critical for the Boreal Zone in which climatic conditions and constraints represent a unique combination of conditions to cope with.

Local plant breeding efforts often focus on developing cultivars of major field crops that are especially adapted to meet the typical local growing conditions (Peltonen-Sainio, Jauhiainen and Venäläinen, 2009; Peltonen-Sainio *et al.,* 2009a). Contrary to regionally adapted cultivars, many European "supranational" cultivars are also recognized and are grown over vast areas under a wide range of conditions. This tendency has strengthened in recent decades and may seriously threaten resilience of cropping systems.

A couple of examples are given that characterize cultivar variability in response to northern growing conditions. When cultivars adapted to northern conditions were compared, it was found that two types of associations existed between plasticity of yield and yield under stressful or favourable conditions for cereals: for spring wheat, oat and six-row barley, high yield plasticity was associated with crop responsiveness to favourable conditions rather than yield reductions under stressful conditions, while in winter wheat and rye, high yield plasticity resulted from the combination of high yield under favourable conditions but low in stressful environments. Evidently the former type of plasticity is the preferred one. Furthermore, modern spring wheat cultivars had higher maximum grain yields compared with older ones at the same level of plasticity (Peltonen-Sainio, Jauhiainen and Sadras, 2011). These examples emphasize the role and opportunities that plant breeding has in contributing to more resilient cropping systems through breeding for less-sensitive cultivars. The concept of "less-sensitivity" may comprise many improved characteristics that are advantageous when targeting improvements for resilience of northern agro-ecosystems: sufficient growing time, lodging resistance, disease and pest resistance, nutrient use efficiency, water use efficiency, tolerance to elevated temperatures, capacity to compete against weeds and overwintering capacity in autumn sown crops *inter alia*. Improvements in many of these traits are also central when aiming at sustainably intensifying northern cropping systems.

Sustainable intensification of cropping systems represents a means to narrow yield gaps in the future. In northern growing conditions, yields of cereals and rapeseed have in many cases stagnated or declined, despite evident progress in genetic yield gains (Peltonen-Sainio, Jauhiainen and Hannukkala, 2007; Peltonen-Sainio, Jauhiainen and Laurila, 2009). This means an increase in the gap between attained and potential yields. In addition to plant breeding, developments in technology and crop management are essential when targeting advances in agriculture through coupling improvements in crop production capacity and competitiveness with environmental benefits. In addition to breeding for more efficient cultivars, one of the evidently most challenging but also promising means to progress along this route is to develop sophisticated water management systems for northern growing areas, which generally have abundant supplies of fresh water.

## 5.2 Increasing diversity of northern cropping systems

**Farm diversity**. Despite the strong, general linkage between weather conditions and yields (Lobell and Field, 2007; Lobell, Cahill and Field, 2007), changes in weather conditions do not solely determine the extent of yield variability. Technological sophistication and developed farming systems may partly alleviate climate-related risks in Europe (Olesen and Bindi, 2002). Farm characteristics, such as intensity of cropping, farm size and land use, contribute to the capacity to resist climate-induced yield variability (Reidsma *et al.,* 2010).

High levels of farm diversity can be considered a means to adapt to and cope with climate change-induced increase in unfavourable conditions related to elevated temperatures and droughts, and thereby reduce vulnerability of yields and improve resilience to climate change (Reidsma and Ewert, 2008). Farm diversity can be expressed at the farm, region, country or climatic zone level (Reidsma and Ewert, 2008). At the farm level, diversity relates to diversity in farming activities. These can include differences in crops grown, degree and means of fertilizer use, pesticide use, irrigation and other basic management practices. As different crops respond differently to climate constraints and variability, greater crop diversity on farms may improve resilience and adaptation to climate change and thereby decrease vulnerability to climatic constraints (Howden *et al.,* 2007).

There are basically two means to diversify cropping systems: by introducing more diverse crop rotations (i.e. having more crop species for cultivation) and/or diversifying within a crop through introducing cultivars differing as much as possible genetically (though not at the expense of adaptation to prevailing conditions) and thereby in their responsiveness to weather conditions (Howden *et al.,* 2007). The latter is a particularly important approach in the case that economic incentives are limited and do not enhance cultivation of a greater number of different crop species. Northern agro-ecosystems are typically dominated by cereal and grass crops (Table 3). In the future, also for northern growing conditions, increases in diversity at the regional and farm scales are more possible owing to prolongation of growing season and concomitant opportunities to introduce novel crops or expand cultivation of current minor crops at the expense of cereal monocultures. Introduction and/or expansion of minor crops to diversify northern agro-ecosystems need, however, to be balanced in the sense that many minor crops (such as rapeseed and grain legumes) may be less well adapted to northern conditions (farmers may be also less used to managing associated responses and risks), which again may be associated with increased crop responsiveness to fluctuating conditions. This again may cause additional fluctuations in yields and does not necessarily result in the expected degree of improvement in resilience. On the other hand, the essential ecological services that diversified crops could provide to northern crop rotations may, in turn, enhance resilience.

Another means of diversifying future cropping systems at high latitudes is by further developing management of winter-sown crops that offer dual-opportunities: not only through their higher yield potential, reduced predisposition to early summer drought, and diversification of crop rotations, but also due to efficient capture of additional nitrogen that is mineralized during warmer autumns (Patil *et al.,* 2010b; Thomsen, Laegdsmand and Olesen, 2010). Results of Patil *et al.* (2010b) underline the importance of integrating winter, catch or cover crops into cereal-based cropping systems to improve resilience to harmful climate-change effects.

Benefiting from cultivar diversity is based on crop responses differing regarding timing of exceptional weather events, such as drought, heavy rains, low and high temperatures, depending on crop and phenotypic stability of the cultivar grown and management practices. In general, there is genetic variation available among current barley germplasm in response to many weather variables, except to waterlogging, early summer drought and high temperature accumulation rate at pre-heading (Hakala *et al.*, 2012). Thus, barley cultivars adapted to northern growing conditions do not have variation in their responses to some of the most critical risks that are likely to characterize changing climate. Weather conditions are also associated with the risk of pest and disease outbreaks and the magnitude of subsequent crop losses and, therefore, cultivar resistance to major diseases is likely to represent another important means to improve resilience. Rötter *et al.* (2011) also underlined that in addition to breeding adapted cultivars, agronomic practices, including crop protection, could help improve resilience and reduce risks of yield losses.

Another means to increase farm diversity in northern conditions is through extensification of cultivation in some areas and/or fields that have low productive capacity or represent especially high risks for the environment. Extensification may be implemented by using fields for production of bioenergy, if rational, or reserving them as naturally managed fields (see Table 5). Another important aspect of farm diversity is that the northernmost European countries are considered to have valuable croplands of high ecosystem quality (contrary to the most intensively cultivated croplands in Europe) and are therefore worth protecting to preserve their agricultural biodiversity (Reidsma *et al.*, 2006). On the other hand, in the future these northern cropping systems may, however, be sustainably intensified owing to higher potential yields in order not to expand the gap between actual and potential yields. This again may leave land for extensification, nature or to be used as naturally managed fields.

**Regional diversity**. At the regional level, diversity means differences in farm intensity, farm size, farm management and cropping systems. Integration of animal husbandry into crop production evidently increases regional diversity. During past centuries agriculture was most vulnerable to crop failures and the Finnish population to famine until animal production was launched as an essential component of Finnish agriculture and especially to buffer against food insecurity (Peltonen-Sainio and Niemi, 2012). In addition to farm characteristics, socio-economic conditions affect the adaptive capacity of agriculture (Reidsma, Ewert and Lansink, 2007). For example, input intensity and economic size influence, in addition to climate and land use, spatial variability in yields and income. Farm characteristics influence climate impacts on crop yields and income and are good indicators of adaptive capacity, and therefore different farm types with different management will adapt differently (Reidsma, Ewert and Lansink, 2007). Reidsma *et al.* (2010) demonstrated that greater diversity in farm types reduced impacts of climate variability on a regional scale, though certain farm types may still be vulnerable within a region.

Reidsma and Ewert (2008) assessed different regions in Europe and established that harmful effects of elevated temperatures were more modest in Mediterranean climates compared with central European temperate regions. Such an advantage was attributed to greater diversity of farms (size, intensity) and associated reduced regional vulnerability of wheat yields to climate variability. In light of this assessment, resilience of agriculture may be increased in Mediterranean regions by this means even though the Mediterranean is considered to be the most vulnerable region to climate change in Europe (Reidsma *et al.,* 2009). In the Boreal region, Finland being an example, agriculture is fragmented as production sectors are divided between the south and north (e.g. field crop versus dairy production regions), which again increases diversity in northern areas of the country while reducing it in southern areas owing to lack of diverse grass mixtures grown in south on a large scale.

## 6. SUMMARY

Northern European crop production may benefit from climate change in the long run, but not without comprehensive and extremely costly adaptation measures. In addition to being expensive, development and implementation of adaptation measures will also take time, which necessitates prompt responses in activating all the processes that target successful adaptation. In the case of northern European agriculture, successful adaptation does not mean that agricultural productivity and food production capacity would be sustained in “business as usual capacities”, but in the case of successful adaptation, northern European agriculture may even increase in productive capacities. On the other hand, there is also more to lose if yield potentials would drastically increase but, owing to more complex, coincident stresses, yields could stagnate or decline from the present levels. The “Stern Review on the Economics of Climate Change” type of analysis is, however, essential to estimate costs and benefits in northern agro-ecosystems. And this can be done today, in the light of recent understanding on anticipated changes in future production potentials as well as requirements for comprehensive adaptation measures.

Implementation of adaptation measures within an adequate time frame represents the avenue to substantially improve resilience of northern cropping systems to future climate. Cropping systems need to be highlighted as a concept because the key issue is not how a single trait or even several essential traits are tailored to a cultivar in order to improve resistance to or tolerance of climatic or other constraints. Such well-adapted cultivars are, however, essential components of larger cropping system, the performance of which must be managed as a whole to provide improved resilience to climate change and variability. Other essential components needed to improve resilience to future northern climates, in addition to well-adapted cultivars, are diversification of crop rotations and alternative crops (including nitrogen-fixing legumes, rapeseed, winter crops), development of water management systems, provision for emerging pests and diseases, planning of regional and farm-scale field use by balancing intensification and extensification, and a halt to further fragmentation of animal and crop farms. Adaptation at the farm scale may have cumulative effects on resilience also at the regional level. All these critical adaptation measures to improve resilience to climate change and variability in northern growing conditions are also essential steps towards sustainably intensified northern agricultural systems.

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# A broad overview of the main problems derived from climate change that will affect agricultural production in the Mediterranean area

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## EXECUTIVE SUMMARY

Climate change refers to present and future changes in climate conditions and is more frequently reflected by increasing average temperature, changes in precipitation and changes in the frequency, intensity, spatial extent, duration and timing of extreme weather and climate events. The Mediterranean region presents wide climate variability but the collective picture is one of substantial drying and warming. Especially in the warm season, precipitation decrease may exceed –25 to –30 percent and warming may exceed 4–5 °C. Extreme events in the Mediterranean region are related to droughts and floods that may give rise to deep erosion and landslides. For these reasons, the Mediterranean region is identified as one of the most prominent hotspots in future climate-change projections. Climate change is assumed to have significant effects on Mediterranean agriculture. Projected climate changes will have a direct impact on water resources and irrigation requirements, crop growth conditions, crop productivity and crop distribution, agricultural pests and diseases, and the conditions for livestock production. These impacts will generate changing land-use patterns and will trigger economy-wide effects.

In the Mediterranean parts of Europe, the declining water balance has been documented over the past 32 years. In certain North African and eastern Mediterranean countries, climate change may result in surface water reductions of more than 35 percent. Rainfed agriculture, which, in certain areas of North Africa represents more than 90 percent of total agricultural land, will be particularly affected. Crop growth will be directly affected by climate change. In southern Europe, general decreases in yield (e.g. legumes –30 to +5 percent; sunflower –12 to +3 percent and tuber crops –14 to +7 percent by 2050) and increases in water demand (e.g. for maize +2 to +4 percent and potato +6 to +10 percent by 2050) are expected for spring-sown crops. However, in the warmer southern Mediterranean, increases in $CO_2$ will help reduce the loss in yield arising from a warmer and drier climate, but will not be able to recover the losses completely. In the cooler northeastern Mediterranean, $CO_2$ increases

associated with climate change will result in little net effect on most crops, provided that the increase in water demand, especially for irrigated crops, can be met. The change in land productivity brought by changing climate conditions may trigger economy-wide effects. In areas with significant productivity losses such as the Mediterranean south and with the agricultural sector still playing a significant role in the overall economy, gross domestic product (GDP) changes are expected to be negative and significant, especially under the A2 scenario.

Climate change will apply an additional stress on rates of land degradation through changes in the length of days and/or seasons, recurrence of droughts, floods and other extreme climatic events, changes in temperature and precipitation, which in turn reduces vegetation cover, water resource availability, soil quality and changes in land-use practices, such as conversion of land use, pollution and depletion of soil nutrients. The impacts of climate change on storm runoff and erosion in Mediterranean watersheds are difficult to assess owing to the expected increase in storm frequency coupled with a decrease in total rainfall and soil moisture, added to positive or negative changes to different types of vegetation cover. However, the most serious effect of climate change and especially of increased temperatures and summer droughts on forest is expected to be the risk of forest fires. Depending on the scenario, it is expected that in southern Europe, climate change will increase forest fires by 10–20 percent.

Resilience refers to actions aiming at building tolerance against the effects of global warming. At farm level, resilience actions include the adoption of drought-resistant crops, the adoption of water-saving cropping methods such as mulching, minimum tillage and maintenance of cover crops, a change in planting dates and cultivars, and even a shift to cropping zones by altitude and latitude. Resilience at farm level should be coordinated and planned to avoid possible internal incoherencies among resilience measures and inconsistencies of resilience with wider rural development objectives. Certain resilience measures are contradicting water conservation objectives while other resilience measures can be better coordinated in the framework of wider objectives such as the soil and water conservation strategies. Taking into account the specificity and diversity of the socio-economic conditions in the Mediterranean basin together with the fact that this region of the world is considered to be a climatic change hotspot, building a resilience strategy is a priority, “no regret” action.

## 1. INTRODUCTION

The aim of this paper is to provide a broad overview of the main problems that will affect agricultural production in the Mediterranean area and are derived by climate change. In this section, the scientific ground of this work is set by presenting the basic definitions and the scientific evidence of the expected significant climate change in the Mediterranean area. In section 2, we provide an overview of potential climate change impacts on agriculture in the context of the Mediterranean area. Section 3 analyses the relationships between climate change, soil erosion and subsequent desertification problems. Section 4 considers the potential impact of climate change on Mediterranean forest with special reference to forest fires, not only on forests but also the important agro-forest systems characterizing this region of the world. Finally, section 5 analyses the strategies that build resilience to climate change in agriculture in the Mediterranean region, while section 6 presents the basic conclusions of this critical review of the literature.

## 1.1 Definitions and the climate change framework

Climate change is an issue of world importance not only because it affects the global physical environment but also because its consequences will spread through planetary economic and social mechanisms to every nation irrespective of the local severity of impacts. A broad definition of climate change is adopted by the Intergovernmental Panel on Climate Change (IPCC), the leading international body for the assessment of climate change. Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether as a result of natural variability or as a result of human activity (IPCC, 2007a). A narrower definition is adopted by the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. In this work we adopt the IPCC definition of climate change and we accept the scientific evidence provided in IPCC's Third Assessment Report (TAR) and Fourth Assessment Reports.

Climate change refers to present and future changes in climate conditions. Present changes are based on observed scientific facts, while future changes are based on projected simulations under various scenarios. Ambiguity rises because of the frequently interchangeable use of these two terms. As concerns the present state, the IPCC is definite by stating that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007a). As a result, the observed climate changes have already produced a series of evident effects and a range of hypothesized effects. As the IPCC states "Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases" while "other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers" (IPCC, 2007a).

Taking into account the chain from greenhouse gas (GHG) emissions to atmospheric concentration, to radiative forcing and climate responses and effects, projections of the future are, primarily, based on scenarios about the likely evolution of GHG emission. The Special Report on Emissions Scenarios (SRES) has devised four families of likely future development pathways (A1, A2, B1 and B2) that include a wide range of demographic, economic and technological driving forces and their consequent GHG emissions but do not include climate policies above current ones. Each one of the four families of scenarios assumes a storyline concerning the likely evolution of demographic, economic and technological parameters. Short- and long-term assessments of future climate change are based on the underlying assumptions of these families of scenarios. Thus, when discussing about future climate change, one should be clearly aware of the underlying hypotheses used to produce such projections. Therefore, it is important to present, very briefly, the hypotheses of the four broad families of scenarios in the words of the SRES.

The A1 scenario adopts a storyline that assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures towards a service and information economy. B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. Also, it is important to note that there is no likelihood attached to any of the SRES scenarios. The influence of these assumptions on the variability of projected global average surface warming and sea level rise by the end of the twenty-first century is very significant. Relative to a 2000 Atmosphere-Ocean General Circulation Model (AOGCM) base, temperature may rise from a low 1.8 °C for the B1 family of scenarios to 4 °C for the A1FI scenario, while the corresponding ranges for sea level rise are from 18 cm to 59 cm (IPCC, 2007b).

Furthermore, a changing climate leads to changes in the frequency, intensity, spatial extent, duration and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events. Thus, future climate-change projections deal with the occurrence and intensity of extreme events that, very frequently, lead to physical disasters. The relationship between climate change and extreme weather and climate events may have severe implications on society and sustainable development, depending not only on the extremes themselves, but also on exposure and vulnerability. According to SREX, climate extremes are defined as "The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as climate extremes" (IPCC, 2012). Some of the expected extreme events are absolutely related to agriculture and forestry and for this reason we present, briefly, the preliminary statements by SREX. First, the SREX states that "It is *virtually certain* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale. It is *very likely* that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas. Based on the A1B and A2 emissions scenarios, a 1-in-20 year hottest day is *likely* to become a 1-in-2 year event by the end of the 21st century in most regions, except in the high latitudes of the Northern Hemisphere, where it is *likely* to become a 1-in-5 year event". Second, the SREX states that "It is *likely* that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe". And is very important to note that "...in some regions, increases in heavy precipitation will occur despite projected decreases in total precipitation in those regions" (IPCC, 2012).

In closing this section we should note that for all aforementioned evidence and future projections for global climate change in general, and for the European climate change specifically, substantial uncertainties remain. Although wide-ranging impacts of changes in current climate have been documented in Europe with very high confidence, uncertainties remain and reflect the sensitivity of the European climate change to the magnitude of the global warming and the changes in the atmospheric circulation and the North Atlantic ThermoHaline Circulation (THC) or, in general, the Atlantic Meridional Overturning Circulation (MOC). Deficiencies in modelling the processes that regulate the local water and energy cycles in Europe introduce uncertainty, for both the changes in mean conditions and extremes. For example, uncertainties emerge from model results that, while agreeing on a large-scale decrease in summer half-year precipitation in South Europe, disagree on the magnitude and geographical details of this change in precipitation patterns. Finally, uncertainty is introduced by the significant natural variability of the European climate.

## 1.2 The Mediterranean area as a climate change hotspot

Owing to the fact that the Mediterranean region lies in a transition climate zone between North Africa and central Europe, it is affected by mid-latitude and tropical processes. The Mediterranean region is also characterized by a complex topography, the presence of a large water body, extensive coastline and vegetation that modulate regional climate signals at small spatial scales. The Mediterranean region also may be influenced by GHG emissions of central Europe, Africa and Asia (Alpert *et al.*, 2006). All the aforementioned factors contribute to a climate of highly diverse types and significant spatial variability.

Concerning present changes to climatic conditions, and according to the National Oceanic and Atmospheric Administration (NOAA), wintertime droughts are increasingly common in the Mediterranean region, and human-caused climate change is partly responsible for this. In the last 20 years, ten of the driest 12 winters have taken place in the lands surrounding the Mediterranean Sea. NOAA (2011) found agreement between the observed increase in winter droughts and in the projections of climate models that include known increases in greenhouse gases. Both observations and model simulations show a sudden shift to drier conditions in the Mediterranean beginning in the 1970s. The analysis began with the year 1902, the first year of a recorded rainfall dataset. Figure 1 summarizes the findings of the NOAA study. As concerns future changes, the IPCC's assessment of projected climate changes in Europe states that annual mean temperatures in Europe are likely to increase more than the global mean and that the warming in the Mediterranean area is likely to be largest in summer (Christensen *et al.*, 2007). The same report acknowledges that the annual precipitation is very likely to decrease in most of the Mediterranean area, while the annual number of precipitations is very likely to decrease and the risk of summer drought is likely to increase. In addition to these changes, the likely occurrence of extreme events, including extreme precipitation or extreme lack of precipitation with high temperature, is expected to increase, leading to high-impact floods and droughts (Kundzewicz, Radziejewski and Pi´nskwar, 2006). Giorgi and Lionello (2008) present the most comprehensive and updated review of climate-change projections over the Mediterranean region based on global and regional climate-change simulations. Figure 2

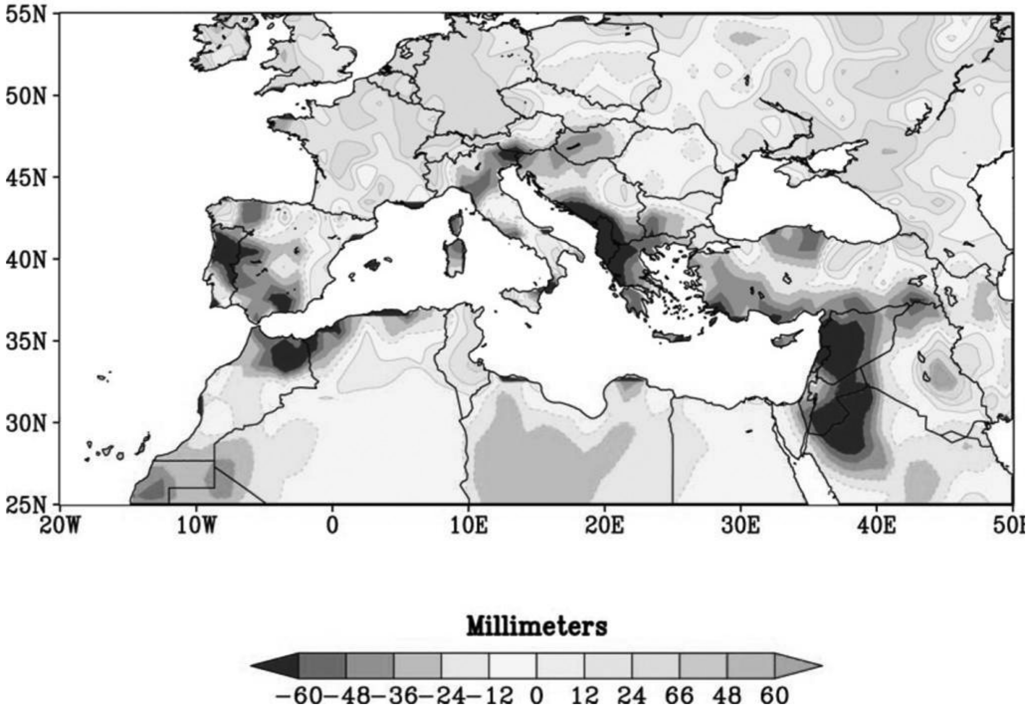


**Figure 1. Greyscales highlight lands around the Mediterranean that experienced significantly drier winters during 1971–2010 than the comparison period of 1902–2010**
*Source*: NOAA (2011).

summarizes Giorgi and Lionello's (2008) findings by European subregions including the Mediterranean area. It is evident that the Mediterranean region presents a wide variability but the collective picture is one of substantial drying and warming. Especially in the warm season, precipitation decrease may exceed –25 to –30 percent and warming may exceed 4-5 °C (Giorgi and Lionello, 2008). Taking a closer look at subregions we realize the significant variability in projections of winter and summer precipitation and air temperature corresponding minimum and maxima.

Hertig and Jacobeit (2008a) found that "temperatures show an increase for the whole Mediterranean area and for all months of the year in the period 2071–2100 compared to 1990–2019 under the B2 scenario conditions, ranging mostly between 2 and 4 °C, depending on region and season". The same authors underlined that: "Even though there is still a high degree of uncertainty regarding the regional distribution of climate change in the Mediterranean area, substantial temperature changes of partly more than 4 °C by the end of this century have to be anticipated under enhanced greenhouse warming conditions." As concerns precipitation, Hertig and Jacobeit (2008b) found that: "under the B2 scenario conditions, a shortening and at the same time an increase in rainfall amount of the wet season arises for the western and northern Mediterranean regions" and "Precipitation increases in winter for the period 2071–2100 compared to 1990–2019, whereas precipitation decreases dominate in autumn and spring. The eastern and southern parts of the Mediterranean area,

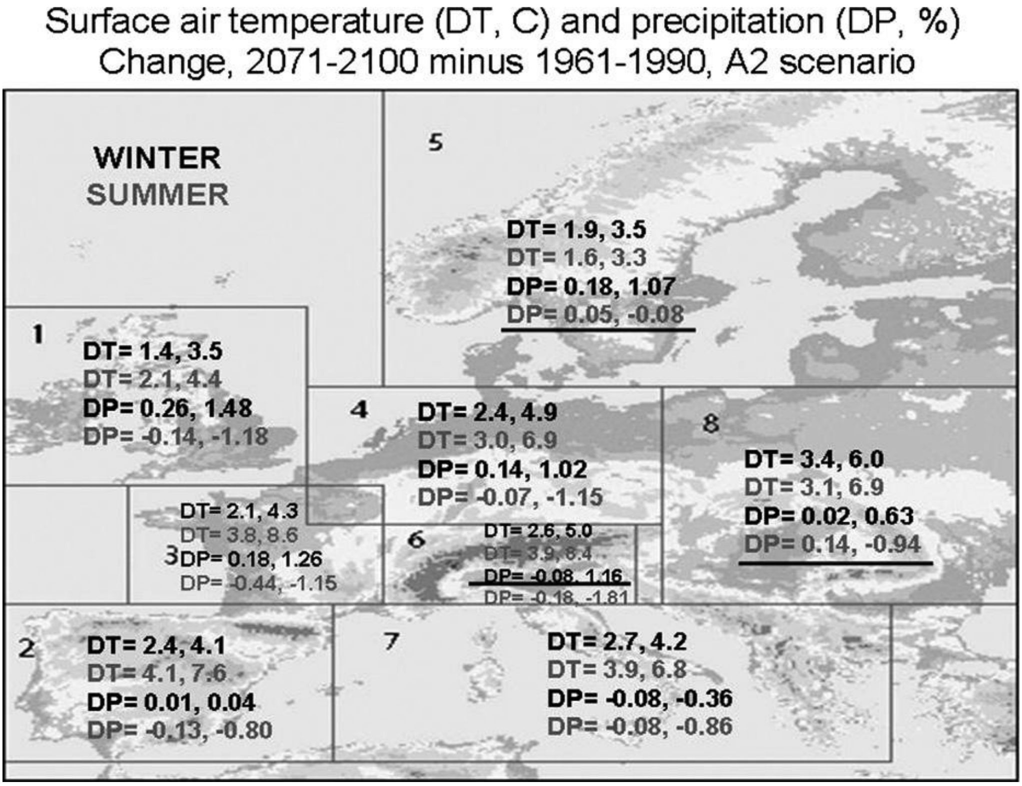


**Figure 2. Minimum and maximum change in surface air temperature (DT) and precipitation (DP) simulated by the ensemble of global and regional climate models in the PRUDENCE project over different PRUDENCE subregions (land only points), 2071–2100 minus 1961–1990, A2 scenario.**
Units are °C for temperature and mm/day for precipitation.
*Source:* Figure 15 in Giorgi and Lionello (2008).

on the other hand, exhibit mainly negative precipitation changes throughout the period from October to May, under enhanced greenhouse warming conditions.”

In North Africa and the Saharan regions, annual mean temperatures are expected to increase by median values of 3.5 and 3.6 °C, respectively, for the A1B scenario, with the largest increases expected during the summer months of June, July, and August (NIC, 2009). Concerning precipitation, the projections are less definitive for North Africa but involve a drying trend, especially along the Mediterranean coast, that is expected to become more pronounced with time. Paeth *et al.* (2009) estimate that by 2050 surface temperatures in North Africa will increase by approximately 1.5 to 2 °C and precipitation will decrease by 10 to 30 percent across many of the desert areas of the region, with larger precipitation decreases of up to 200 percent along the coasts of Morocco, Algeria and Tunisia. Similar projections prevail for the southeast Mediterranean region including Israel, Lebanon, Cyprus and parts of southwest Turkey.

Giorgi and Lionello (2008) also review the likely occurrence of extreme events and conclude that “High temperature extremes and drought events were found to increase substantially in summer while winter low temperature extremes were found to decrease”

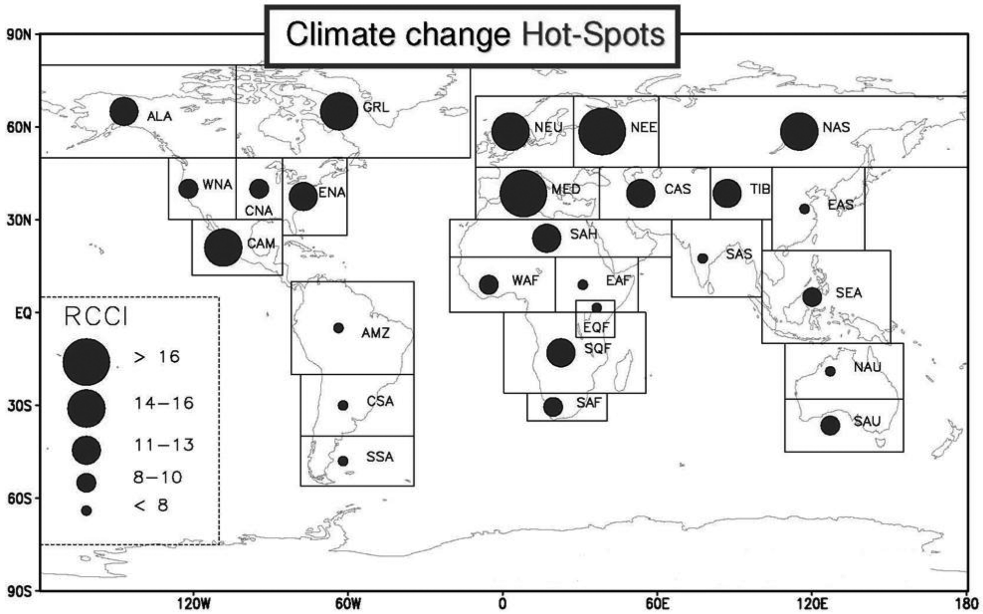


**Figure 3. Climate change hotspots**
*Source:* Giorgi (2006).

while, “On a yearly basis, a prevailing increase in precipitation extremes over the Mediterranean was found, particularly over and around the Alpine region”. Thus, extreme events are related to droughts and floods and the likely occurrence of both, i.e. extreme precipitation events after prolonged droughts that may give rise to more extreme phenomena such as deep erosion and landslides. Hertig, Seubert and Jacobeit. (2010) conclude that: “the intra-annual extreme temperature range will decrease in large parts of the Mediterranean area during the 21st century under enhanced greenhouse warming conditions. This is most pronounced for the eastern Mediterranean area. Thus, extreme minimum temperatures in winter are found to increase in the range of up to about 0.25 °C over the Iberian Peninsula and up to 1 °C in the eastern Mediterranean area. Extreme maximum temperatures in summer show a slight negative trend over the Iberian Peninsula, increases of up to 0.25 °C in the south-eastern Mediterranean area, and the maximum increase of about 0.5 °C mainly in the central-northern Mediterranean area.”

Besides projections about the mean values of temperature and precipitation as well as their extreme occurrences, other climate change phenomena may be proved of significant importance for the Mediterranean region. It is hypothesized that around much of the Mediterranean basin, sea levels could rise by close to 1 m by 2100. As a consequence, some lowlying coastal areas would be lost through flooding or erosion, while rivers and coastal aquifers would become more salty (Karas, 1997). The worst affected areas will be the Nile Delta (Egypt), Venice (Italy) and Thessaloniki (Greece) where local subsidence means that sea levels could rise by at least one-and a-half times as much as elsewhere.

The Regional Climate Change Index (RCCI) is based on temperature and precipitation mean changes and changes in their interannual variability. Taking into account the aforementioned evidence and projections, it does not come as a surprise that the Mediterranean region emerges as the primary hotspot among the other regions of the globe, having the highest RCCI, indicating a comparatively more receptive region to climate change. Thus, the identification of the Mediterranean region as one of the most prominent hotspots in future climate change projections by Giorgi (2006) is fully justifiable (Figure 3).

## 2. CLIMATE CHANGE EFFECTS ON MEDITERRANEAN AGRICULTURE

The observed and projected climate change in the Mediterranean region as presented in this work, points to increased temperature, decreased precipitation and expected sea level rise. Iglesias *et al*. (2007) reviewed, among others, the main risks to agricultural production imposed by climate change in Europe and concluded that these risks results from changes in the following factors:

1. water resources and irrigation requirements;
2. soil fertility, salinity and erosion;
3. crop growth conditions, crop productivity and crop distribution;
4. land use;
5. optimal conditions for livestock production;
6. agricultural pests and diseases; and
7. increased expenditure on emergency and remediation actions.

### 2.1 Water resources and irrigation requirements

Water resources and irrigation requirements will be affected by two climate change processes. First, the simultaneous changes in annual totals of precipitation and of average air temperatures will affect hydrological regimes with an immediate impact on the use and distribution of water within agricultural uses. Second, the seasonality of precipitation and interannual variability may affect crop yields, crop quality and even crop choice. Taking account of past and present water demand, on average, the rate of increase in water demand is around 50 m$^3$/ha/year in Europe. However, in some cases (Italy, Greece, Maghreb, central Spain, southern France and Germany) water demand is more than 150–200 m$^3$/ha/year (Lavalle *et al.,* 2009). In the Mediterranean parts of Europe, the declining water balance has been documented over the past 32 years. Taking into account that demand for irrigation water in southern Europe and the Mediterranean area is already very high, under drier conditions more water will be required per unit area, and peak irrigation demands are expected to rise owing to droughts and high temperatures putting crops under severe stress. Decreased availability of water may lead to insufficient water being available for irrigation, resulting in crops suffering moisture stress. At the same time, severely dry conditions will alter the physical properties of soils, and especially soil structure, adding stress to the already strained plants.

North Africa accounts for more than 41 percent (about 6 million hectares) of total irrigated lands in Africa. The Northern region represents more than half of the agricultural water withdrawal of the continent (NIC, 2009). Egypt is a clear example where hydro-intensive crops contribute to the country’s agricultural exports and create income for smallholders. A changing climate, together with the expansion of cultivated areas in the country, will imply additional stress on water resources and will bring negative effects on agriculture and its economy. Tunisia is also experiencing persistent droughts. Rainfed agriculture represents 90 percent of the country's agricultural area, exposing this sector to climate variability. Cereals are important for Tunisia primarily (97 percent) cultivated under rainfed conditions. In the late 1990s, water reserves did not satisfy the water needs of both Tunisia and Morocco, which caused several irrigation-dependent agricultural systems to cease production.

For Cyprus, a 15 percent decrease in precipitation from 540 mm to 460 mm (15 percent) could lead to a 41 percent decrease in water resources (Bruggeman *et al.,* 2012) with serious impacts on agriculture, taking into account that agriculture in Cyprus uses more than half of the available freshwater. In Israel, the 2010 Climate Change Report of the Ministry of Environmental Protection pointed out that potential impacts of climate change on water may include an increase in the frequency and severity of floods, which may cause major damage to property and people, a 25 percent reduction in water availability for 2070–2099 in comparison with 1961–1990, a reduction in groundwater recharge, a loss of an estimated 16 million $m^3$ of water for each kilometre along the coastal plain as a result of a potential rise in sea level of 50 cm and changes in the salinity level of the Sea of Galilee, the major freshwater supplier of the country (Shachar, 2011). In Turkey, the likely consequences of climate change on surface waters were examined using a water budget model for the Gediz and Büyük Menderes Basins along the Aegean coast. As the European Environment Agency (EEA) indicates in its Country Assessment Reports, the results showed that by 2050, water runoff will be reduced by 35–48 percent, potential evaporation will increase by 15–17 percent, crop water demand will increase by 19–23 percent and surface waters will be reduced by about 35 percent.

## 2.2 Soil fertility, salinity and erosion

Owing to the fact that soil degradation and the consequent risk of desertification are major problems especially in the Mediterranean area, and are issues impacting land use far beyond agriculture and forestry, section 3 of this report is solely devoted to an examination of climate change impacts on soil erosion and desertification. Iglesias *et al.* (2007) detail a range of soil conservation problems including high erosion rates (and erosion-derived agro-chemical pollution of waterways), declines in soil organic matter and vulnerability of soil organic carbon pools, which are linked to site factors and changing land management practices but will be exacerbated by climate change and the increasing incidence of extreme weather events.

## 2.3 Crop growth, productivity and distribution

Crop growth conditions and crop productivity are interrelated issues. Basically crop growth is affected by climate conditions, $CO_2$ concentration and technology. Concerning climate conditions, the basic variables are precipitation and air temperature that control soil moisture and water availability to plants and affect evapotranspiration. In addition, other variables such as wind velocity, the occurrence of early frosts or ice and the time occurrence of extreme phenomena are important as they can exercise significant stress on plants and put production at risk. Ewert *et al.* (2005) argue that, for all the above factors, technology is so important that it can outweigh all the negative impacts brought by climate change. Alcamo *et al.* (2007) reviewed studies concerning the impacts of climate change on crop production in Europe and concluded that in Southern Europe, general decreases in yield (e.g. legumes –30 to +5 percent; sunflower –12 to +3 percent and tuber crops –14 to +7 percent by 2050) and increases in water demand (e.g. for maize +2 to +4 percent and potato +6 to +10 percent by 2050) are expected for spring-sown crops (Giannakopoulos *et al.*, 2005; Audsley *et al.,* 2006).

The impacts on autumn-sown crops are more geographically variable; yield is expected to decrease strongly in most southern areas, and increase in northern or cooler areas (e.g. wheat: +3 to +4 percent by 2020, –8 to +22 percent by 2050, –15 to +32 percent by 2080) (Santos, Forbes and Moita, 2002; Giannakopoulos *et al.*, 2005; Audsley *et al.,* 2006; Olesen *et al.,* 2007). Alcamo *et al.* (2007) also argue that in the European Mediterranean region, increases in the frequency of extreme climate events during specific crop development stages (e.g. heat stress during flowering period, rainy days during sowing time), together with higher rainfall intensity and longer dry spells, are likely to reduce the yield of summer crops (e.g. sunflower).

Jones and Thornton (2003) examined the potential changes in maize production, the most important crop for smallholders. Climate change in Africa and Latin America, including Morocco, modelled using the HadCM2 simulated changes in temperature and precipitation for the period 2040–2069 ("2055"). These climate projections were used by the CERES-Maize crop model to simulate the growth, development and yield of maize crops. For Morocco in 2055, the model predicted a substantial increase in maize crop yield owing to the effects of climate change, from a baseline value of 317 kg/ha to a value of 550 kg/ha, an approximately 175 percent increase. The positive effects of increased atmospheric $CO_2$ concentrations may be the dominant influence on future maize crop yield in Morocco.

In Israel, recent studies suggest that over the period up to 2020 climate change could be beneficial to agriculture, as a result of Israel's Israel to supply international markets earlier in the season (Fleischer, Lichtman and Mendelsohn, 2008), although this result is disputable in some models (Kan, Rapaport-Rom and Shechter, 2007). Bruggeman *et al.* (2012) estimated climate change projections for Cyprus from an ensemble of six Regional Climate Models, under the IPCC-SRES medium A1B emission scenario, which indicated an increase in temperatures and highly variable but slightly lower precipitation amounts for the 2013/14≠2019/20 seasons. They simulated two climate scenarios, one worst-case scenario, represented by the seven dry years from the 1980/81–2008/09 record and a medium scenario made up of three dry years, two average years and two wet years, each with the highest evapotranspiration rates within their class. For both scenarios, irrigation water demand was reduced to 129X106 $m^3$/year, as recommended by recent national water management policies, which was achieved by reducing all irrigated crop areas of the 2010 Cypriot Agricultural Payments Organization (CAPO) crop areas by 25 percent. The computed annual national crop production for 2013/14-2019/2020 was reduced by 41 percent, on average, under scenario 1 and by 43 percent under scenario 2, relative to 1980/81–2008/09. The average loss of irrigated production was 193X103 tonnes/year under scenario 1 and 216X103 tonnes/year under scenario 2, whereas the average rainfed production loss was 132X103 tonnes/year (scenario 1) and 125X103 tonnes/year (scenario 2).

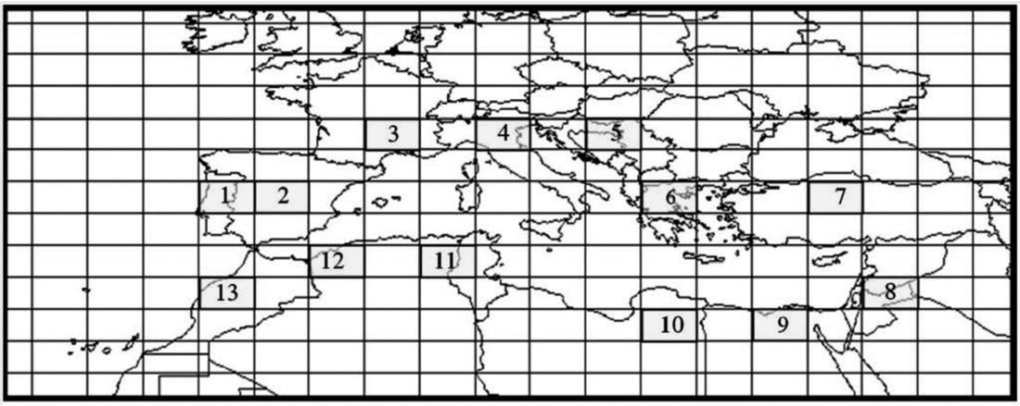


**Figure 4. Grid cells of HadCM3 selected for the impact assessment on agriculture by the Giannakopoulos *et al.* (2009) study**
*Source*: Panel 2 in Giannakopoulos *et al.* (2009).

Giannakopoulos *et al.* (2009) provide the most comprehensive, comparative study of climatic changes over all countries in the Mediterranean basin in 2031–2060, with a 2 °C global warming scenario, investigated with the HadCM3 global circulation model. They examined precipitation and surface temperature changes through mean and extreme values analysis, under the A2 and B2 emission scenarios. Figure 4 shows the 13 grid cells (called hotspots) of the HadCM3 that were selected to provide a homogenous cover of Mediterranean basin and where changes in precipitation and temperature patterns are expected to be substantial, according to HadCM3 model simulations. Over the land areas, the warming is larger than the global average. The rate of warming is found to be around 2 °C in spring and winter, and reached 4 °C in summer. An additional month of summer days is expected, along with 2–4 weeks of tropical nights. Increase in heatwave days and decrease in frost nights are expected to be a month inland. In the northern part of the basin, the widespread drop in summer rainfall is partially compensated by a winter precipitation increase. One to three weeks of additional dry days lead to a dry season lengthened by a week and shifted towards spring in the south of France and inland Algeria, and autumn elsewhere. In central Mediterranean area, droughts are extended by a month, starting a week earlier and ending three weeks later.

In Giannakopoulos *et al.* (2009), crop yields are assessed through the CROPSYST model and HadCM3 data including minimum and maximum temperatures, rainfall and global radiation. CROPSYST simulates crop productivity under selected present and future climate scenarios under a multiyear, multicrop, daily time-step crop growth simulation model, which simulates the soil water budget, the soil–plant nitrogen budget, crop canopy and root growth, crop phenology, dry matter production, yield, residue production and decomposition, and erosion. It is important to note that this model allows the user to specify management parameters such as sowing date, cultivar genetic coefficients, soil profile properties, fertilizer and irrigation management, tillage and atmospheric $CO_2$ concentration in order to simulate resilience-adaptation and mitigation measures. CROPSYST simulates changes in mean climate conditions and not the occurrence of extreme events. Also, it is important to note that CROPSYST, as many models under this family of simulation models, are first calibrated to fit as much as possible the data reported on the FAOSTAT database. Giannakopoulos *et al.* (2009) calculated, for each hotspot and crop type, the annual values of development stages and yields for the two time-slices (1961–1990 and 2031–2060). For the present climate, the simulation runs were performed setting the atmospheric concentration of $CO_2$ at 350 ppm and for the future climate scenarios were performed with increasing $CO_2$ (470 ppm under scenario B2 and 520 ppm under scenario A2). In this study, the CROPSYST model was rerun introducing adaptation management strategies (e.g. changes in sowing dates, cultivar, etc.) that may reduce the negative impact of climate change or enhance positive impacts. In all simulations under this study, the C4 summer crops and tuber crops were considered as "irrigated crops", whereas the rest of the crops were considered as "rainfed crops". Nitrogen was considered not limiting for all the crops.

Figure 5 from Giannakopoulos *et al.* (2009) shows that the impacts of these climatic changes on crops whose growing cycle occurs mostly in autumn and winter showed no changes or even an increase in yield. In contrast, summer crops showed a remarkable decrease in yield. This different pattern is attributed to a lengthier drought period during summer and to an increased rainfall in winter and autumn. The authors draw two very significant conclusions, one concerning climate change impacts without the presence of any adaptation practice and one under adaptation practice (adaptation on-off). Giannakopoulos *et al.* (2009) examine five categories of plants: C4 summer crops – plants that produce a four carbon molecule and for which increased $CO_2$ has little effect on the rate at which photosynthesis occurs, such as sorghum; legumes – plants capable of fixing atmospheric nitrogen, such as beans, peas and alfalfa; C3 summer crops – plants that produce a three carbon molecule, are very responsive to $CO_2$ levels and photosynthesize at a faster rate under increased $CO_2$ concentrations, such as rice, wheat and soybeans; tuber crops such as potatoes; and cereals (the interested reader is refereed to Gillis, 1993 for a review of the evolution of C3 and C4 plants). Without adaptation they found that "the effect of climate change on agriculture is likely to be more severe in the southern Mediterranean areas than in the northern temperate areas. In the warmer southern Mediterranean, increases in $CO_2$ help reduce the loss in yield arising from a warmer and drier climate, but are not able to completely recover the losses. In the cooler north-eastern Mediterranean, $CO_2$ increases associated with climate change result in little net effect on most crops, provided that the increase in water demands, especially for irrigated crops, can be met".

Iglesias *et al*. (2011a) selected nine sites to represent the major agroclimatic regions in Europe. At each site, they simulated crop response to climate and management by using the DSSAT crop models of the International Consortium for Agricultural Systems Applications (ICASA) for wheat, maize and soybeans. Simulated wheat responses to climate are representative of possible responses of winter cereals in all regions and winter and spring cereals in the Mediterranean regions. The authors selected these crops because they are representative of approximately two-thirds of arable land in most regions of Europe and have been used on numerous occasions to represent world food production. As concerns crop productivity, the authors conclude that "crop productivity increases in northern Europe and decreases in southern Europe".

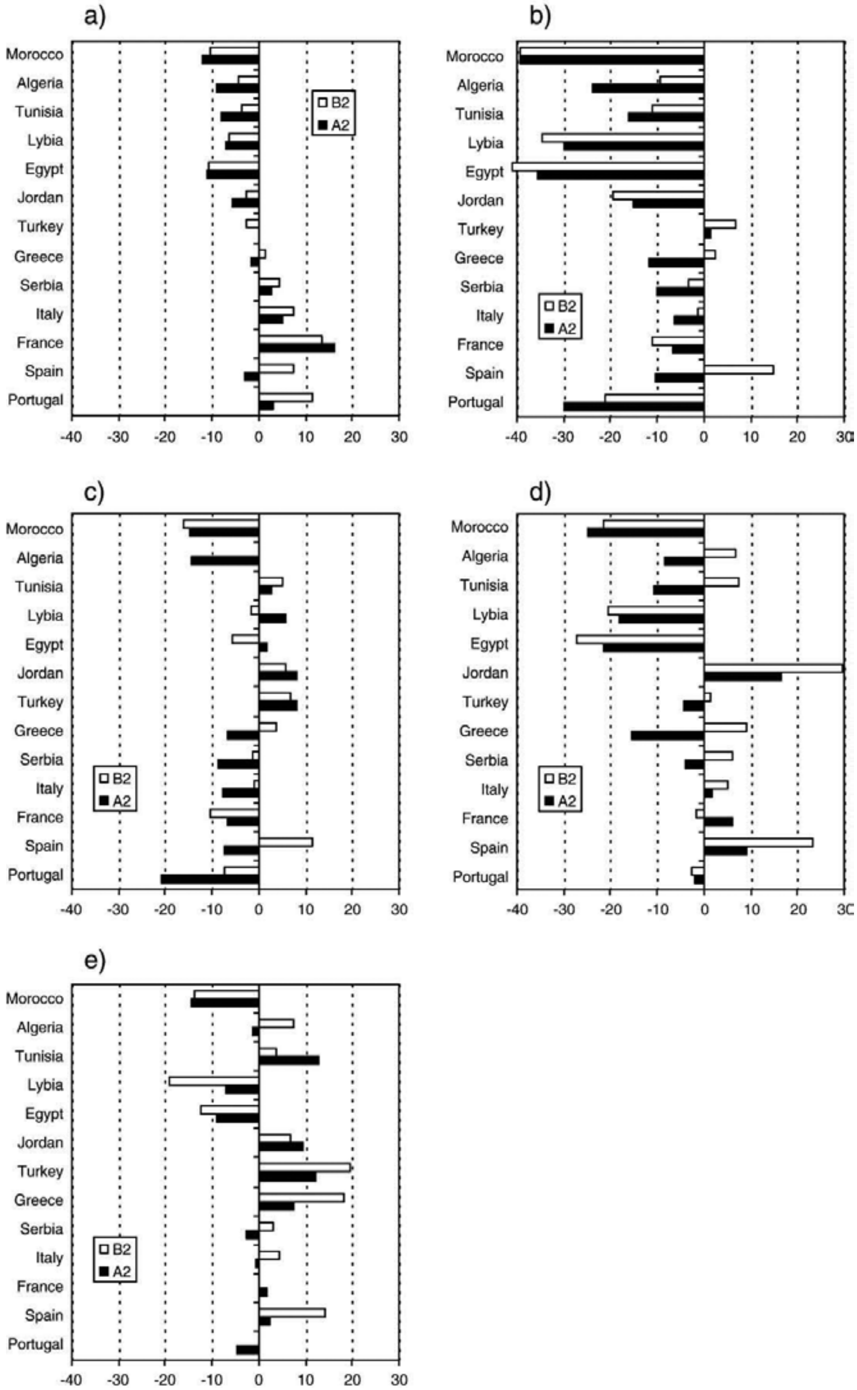


**Figure 5. Impact of climate change on crop productivity for: (a) C4 summer crop, (b) legumes, (c) C3 summer crop, (d) tuber crops, (e) cereals**

The changes in the figure are expressed as percentage differences between future (both A2 and B2 scenarios) and present yields.
*Source*: Figure 9 in Giannakopoulos *et al.* (2009).

Based on observations, experiments and model analyses carried out by the National Institute for Agricultural Research in Morocco, several potential changes to agricultural growing seasons in Morocco were outlined in Morocco's First National Communication to the United Nations Framework Convention on Climate Change (Kingdom of Morocco, 2001). Likely changes in the twenty-first century include a reduction in the growth period of regional crops, a reduction in the duration of crop cycles, and an increase in the risk of dry periods during the course of crop cycles. Hegazy *et al.* (2008) investigated the influence of increased air temperatures associated with future climate change on the spatial and temporal distribution of four crops in Egypt through 2100. Analysis focused on cotton, wheat, rice and maize. Air temperature patterns in Egypt for 2025, 2050, 2075 and 2100 were simulated using a database of information compiled from multiple GCMs run under the B2 emissions scenario. Crop simulations were based on the optimum air temperatures for maximum growth of cotton, wheat, rice and maize throughout the agricultural season, which are 23.0 °C, 16.8 °C, 25.8 °C, and 26.0 °C, respectively. The study showed that a shift in crop sowing dates to earlier in the season, to prevent crop losses due to excessively warm growing conditions, is very likely. Compared with the reference sowing year of 2005, the model study predicted future sowing dates will shift one to eight weeks earlier, depending on the crop type, region and year. The exception is rice sowing in Upper Egypt, which is expected to shift one week later in 2025 and remain unchanged in 2050 and 2075. Wheat is the most sensitive of the four analysed crops to changing temperatures, and the models estimate that by 2100 air temperatures will be so high that growing wheat in Egypt will be impossible.

## 2.4 Land-use impacts

Crop yields under climate change are determined by changing environmental growth conditions (precipitation, air temperature, extreme events and elevated $CO_2$ concentrations) as these are projected in each of the four basic SRES scenarios. In addition, crop production is also determined by global demand and supply factors and the available technology. One issue still to be resolved concerns the effects of changing crop yields on land-use patterns. In other words, how one can model the implications of changes in crop productivity induced by climate change on land-use allocation. As an example of the limitations and uncertainty of the results of such models, one attempt to project changing land-use patterns under climate change was reviewed. This model does not explicitly address Mediterranean agriculture but includes the Mediterranean region as part of a wider European study.

Rounsevell *et al.* (2005) employed a supply and demand model for agriculture for 15 European Union countries plus Norway and Switzerland under four market scenarios (A1FI, A2, B1, B2). This resulted in an assessment of the total area requirement (quantity) of agricultural land use (ha) at the European scale, as a function of changes in relevant drivers including: world supply and demand trends, market intervention through agricultural policy, rural development policy, environmental policy, EU enlargement, land resource competition (e.g. urbanization, recreation, bioenergy crops), the role of the World Trade Organisation (WTO) and climate change through its effect on crop productivity. The quantities of agricultural areas were then spatially distributed (disaggregated) across the European territory using spatial allocation rules. For the A1FI scenario, a globally and economically orientated scenario, the authors assumed all agricultural production to be centred on optimal locations. This generates a pattern of land-use change that is spatially uneven and which favours good production areas over poorer quality regions. Thus, allocation of the decline in land areas estimated at the European scale is assumed to be first taken up by the less favoured areas of the EU (LFAs) and any remaining declines are then accounted for non-LFA areas. For the A2 scenario, all land area changes were distributed equally between the European regions to take account of a certain degree of regional protectionism for reasons of national food security. For the B1 scenario, which is an environmentally and equity-orientated scenario, the authors allowed for oversupply for benefiting and maintaining farmers' incomes and rural communities. Thus, for B1 the authors allowed no decline in grassland but assumed cropland production to be located on optimal locations, as for the A1FI scenario. For the B2 scenario the authors assumed a B1 situation with the addition of no declines in cropland. The authors assumed that the oversupply associated with this scenario would be offset by policy measures that seek to reduce productivity by encouraging extensification and organic production.

Figure 6 shows the decline in cropland and grassland under the four scenarios after Rounsevell *et al.* (2005). Cropland areas decline substantially by 2080 for the A1FI and A2 scenarios. Cropland decline for the B1 scenario is less severe and for the B2 scenario is the smallest because, although cropland areas are assumed constant, some cropland area for food production is replaced by bioenergy production. Declines in the grassland areas for A1FI and A2 are even higher. Changes in grassland areas for the B1scenario are the least severe because of assumed protection policies, while changes for the B2 scenario reflect, as in the case of cropland, a switch from food to bioenergy production.

Rounsevell *et al.* (2005) provide a breakdown of the scenario results of Figure 6, by country for cropland and grassland in 2080. Table 1 shows the estimated regionalized decline in cropland for selective Mediterranean European countries. For the A1FI scenario, the authors conclude that countries in the south of Europe, such as Spain (–74 percent), Portugal (–73 percent) and Greece (–68 percent), experience very large declines in agricultural areas that are much greater than the European-wide changes presented in Figure 6. As they argue, "this reflects the potential for regional disparities within a globally

**Table 1: Share of cropland out of total land for the baseline and the four SRES scenarios in Mediterranean countries and Europe**

| | Baseline (%) | A1FI in 2080 (%) | A2 in 2080 (%) | B1 in 2080 (%) | B2 in 2080 (%) |
|---|---|---|---|---|---|
| Portugal | 26.98 | 7.24 (–73) | 14.22 (–47) | 12.49 (–54) | 17.23 (–36) |
| Spain | 33.17 | 8.78 (–74) | 17.54 (–47) | 17.23 (–48) | 23.69 (–29) |
| France | 45.87 | 26.70 (–42) | 24.71 (–46) | 32.91 (–28) | 32.52 (–29) |
| Italy | 39.53 | 20.13 (–49) | 20.87 (–47) | 25.57 (–35) | 27.21 (–21) |
| Greece | 25.66 | 8.18 (–68) | 13.50 (–47) | 13.96 (–46) | 17.30 (–33) |
| Europe 17 | 23.02 | 12.27 (–47) | 12.66 (–45) | 16.01 (–30) | 16.65 (–28) |

Note: Numbers in parentheses are percentage decline from baseline.
*Source*: Selective data from Table 8 in Rounsevell *et al.* (2005).

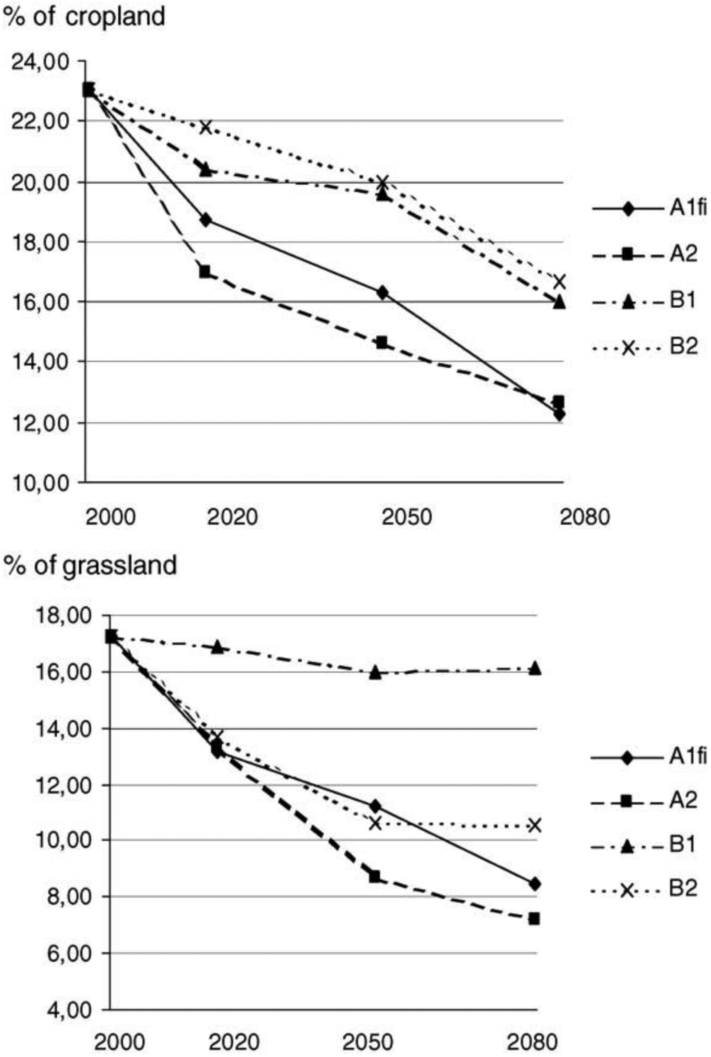


**Figure 6. Changes in cropland and grassland under the four climate change scenarios as percentage of total European area**
*Source*: Figures 2 and 3 in Rounsevell *et al.* (2005).

orientated scenario". Of course, such a result opens a discussion concerning the future of this potentially surplus agricultural land. And, while it may be argued that agricultural land will be converted to recreational areas (including golf-courses and other sport utilities, fields for horse riding and camp sites), this may be true only for central and northern Europe. In the Mediterranean region, with such a projected stress on water resources, this land-use change is rather unlikely, and there may be a change to forest land use. On the other hand, the scenarios presented by Rounsevell *et al.* (2005) have assumed that bioenergy production will take up a certain proportion of the surplus agricultural land but again this will put more stress on the already limited water resources. Finally, Rounsevell *et al.* (2005) suggest that potential structural changes in the farming sector such as increasing farm sizes might represent an appropriate adaptation strategy to land-use change pressures.

## 2.5 Livestock production

Concerning livestock production, Iglesias *et al.* (2007) argue that "a warmer and drier climate may reduce forage production leading to changes in optimal farming systems and a loss of rural income in areas dependent on grazing agriculture". As Olesen (undated) in the foresight section of the Standing Committee on Agricultural Research (EU) web site reports: "higher temperatures result in greater water consumption and more frequent heat stress, which causes declines in physical activities, including eating and grazing. Livestock production may therefore be negatively affected in the warm months of the currently warm regions of Europe". Climate change impacts will probably be minor for intensive livestock systems (e.g. confined dairy, poultry and pig systems) because climate is controlled to some degree.

## 2.6 Agricultural pests and diseases

Climate change and especially higher air temperatures will create conditions suitable for the invasion of weeds, pests and diseases adapted to warmer climatic conditions. The speed at which such invasive species will occur depends on the importance of climatic change, the dispersal rate of the species and on measures taken to combat non-indigenous species (Anderson *et al.*, 2004). The dispersal rate of pests and diseases is most often so high that the geographical extent is determined by the range of climatic suitability (Baker *et al.*, 2000). The Colorado beetle, the European cornborer, the Mediterranean fruit fly and karnal bunt are examples of pests and diseases that are expected to have a considerable northward expansion in Europe under climatic warming. Alcamo *et al.* (2007) review the relevant literature and argue that: "increasing temperatures may also increase the risk of livestock diseases by (i) supporting the dispersal of insects, e.g., *Culicoides imicola*, that are main vectors of several arboviruses, e.g., bluetongue (BT) and African horse sickness (AHS); (ii) enhancing the survival of viruses from one year to the next; (iii) improving conditions for new insect vectors that are now limited by colder temperatures".

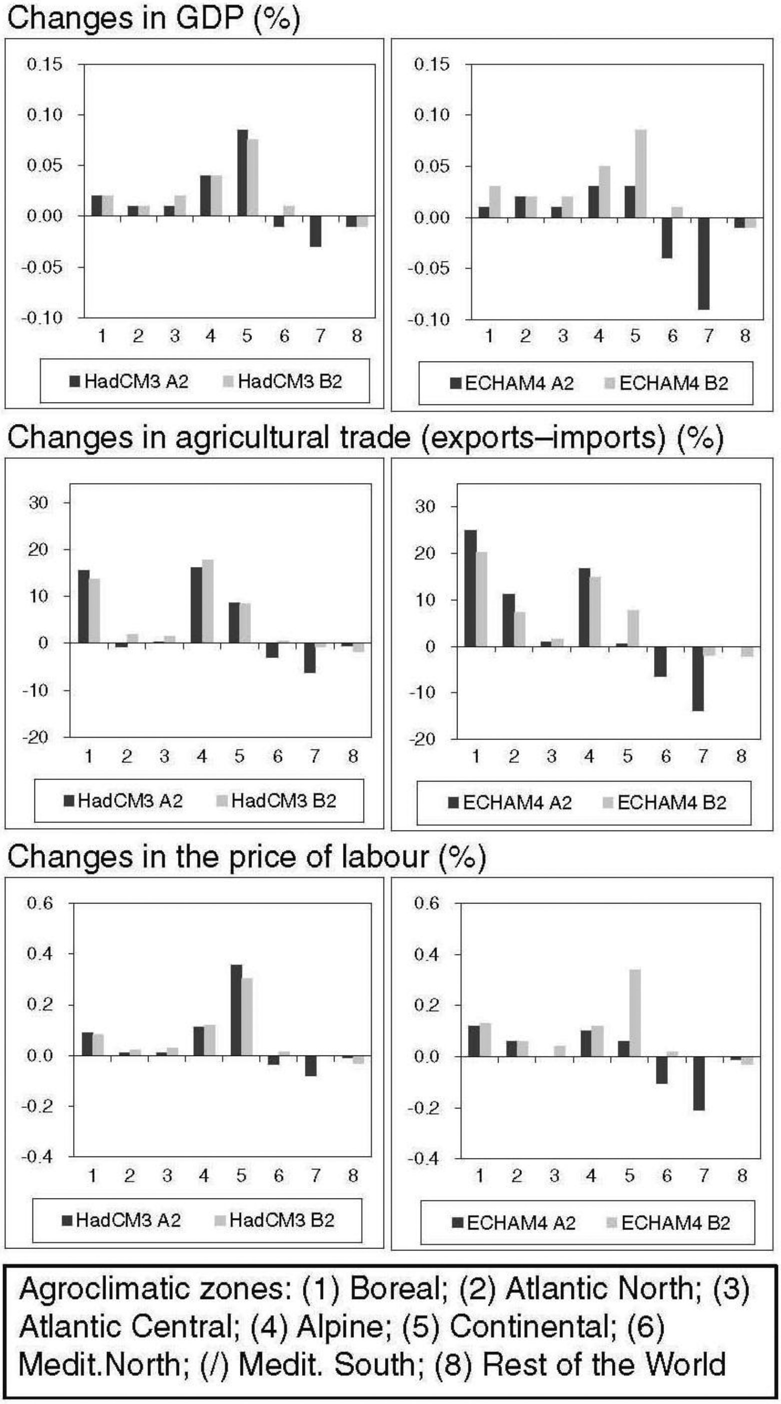
## 2.7 Economy-wide effects

A shift in the location of optimal conditions for specific crop or livestock production systems may lead to a loss of rural income and soil deterioration in the areas where those modes of production can no longer be maintained. Such losses of established farming practices may lead, among others, to land abandonment and increased risk of desertification with a high probability of occurrence during the twenty-first century (Iglesias *et al.*, 2007). In addition, rising sea levels may also lead to significant land-use changes. It is argued that an indirect effect on agriculture may occur if rising sea levels make population centres uninhabitable. The displaced populations will need to be housed and at least some of the housing is likely to be built on agricultural land. It is estimated that about 72 percent of the dwellers in African cities live in slums that have particularly poor drainage facilities and are quite often prone to rising sea levels, which could affect many of the regions' coastal cities, particularly in low-lying areas in Egypt, Tunisia and Morocco. As an example, in Egypt, there is increasing concern about how rises in sea levels might impact the Nile Delta. It has been estimated that a sea level rise of 50 cm in the Delta could displace over 2 million people, flood 1 800 km$^2$ of cropland, and generate some USD35 billion in damage in terms of loss of land, property and infrastructure (OSS/UNEP, 2010). Finally, we should be aware that climate change impacts on agricultural activity will have economy-wide impacts triggered by changes in crop productivity. Unfortunately, research in this area is rather limited for the Mediterranean region and we can rely on published work that includes the European Mediterranean part of the region. Iglesias *et al.* (2011a) use a Computable General Equilibrium (CGE) model based on the Global Trade Analysis Project (GTAP) CGE system for seven European regions, four sectors (crops, other agrarian goods, manufacturing and services) and four factors (land, labour, capital and energy). Of the seven European regions, two represent European Mediterranean areas, namely the Mediterranean North (France and Portugal) and the Mediterranean South (Cyprus, Greece, Italy, Malta and Spain). Crop productivities are estimated under the A2 and B2 scenarios using the DSSAT model, NOAA climate data and EUROSTAT crop distribution and production data. Technological change is modelled with an improvement of 1 percent per year in 2001 and an exponential slowdown in productivity per decade. None of the simulations considered any restrictions on water use for irrigation or application of nitrogen fertilizers. The external shock to the system comes from land productivity changes as a result of climate changes. This will have an effect on input prices that may trigger price changes in agricultural goods that are spread to the other sectors of the economy through various channels such as changes in wages.

Figure 7 shows these changes for the gross domestic product (GDP), agricultural trade and the price of labour. The effects of climate change on GDP depend basically on two factors: first, negative or positive productivity changes owing to modified climate conditions; second, the importance of the agricultural economy in terms of its share in the overall economy. Thus, in areas with significant productivity losses such as the Mediterranean south, and with the agricultural sector still playing a significant role in the overall economy, GDP changes are negative and significant especially under the A2 scenario (upper part of Figure 7). Of course, the effects on GDP are much lower (positive or negative) than the respective changes in land productivity. As the authors note, changes in agriculture imports and exports are wider than the changes in GDP. The agricultural trade balance would increase because of the lower crop prices induced by land productivity gains. These lower prices assign a competitiveness gain for European crops in world agriculture markets. However, in the Mediterranean regions, the crop supply changes are negative, which result in higher prices and no gains for the agricultural trade balance (middle part of Figure 7). Especially in the Mediterranean south, the agricultural trade balance under the A2 scenario may deteriorate by almost 10 to 15 percent depending on the climate model (HadCM or ECHAM). The price of labour moves in the same direction as land productivity (lower part of Figure 7).

## 3. CLIMATE CHANGE AND SOIL DESERTIFICATION IN THE MEDITERRANEAN AREA

The issue of land degradation and desertification in the Mediterranean region was briefly presented in section 2.2 above, but, owing to its significant importance, this section of the paper provides a more comprehensive review of the relevant literature. The issue


Changes in GDP (%)

Changes in agricultural trade (exports–imports) (%)

Changes in the price of labour (%)

Agroclimatic zones: (1) Boreal; (2) Atlantic North; (3) Atlantic Central; (4) Alpine; (5) Continental; (6) Medit.North; (/) Medit. South; (8) Rest of the World

**Figure 7. Economy-wide implications of climate induced changes in land productivity**
*Source*: Figure 6 in Iglesias *et al.* (2011a).

of desertification is not new but only very recently have serious efforts been made to identify and understand the driving forces and processes as well as the implications of land degradation. The term "desertification" refers to land degradation in arid, semi-arid and dry subhumid areas resulting from climate variations and human activity. The most significant aspect of land degradation is the decline in soil fertility and soil structure and the consequent reduction of the land's carrying capacity for plants, animals and humans. This leads to widespread poverty, overexploitation and ultimately destruction and abandonment of land (Wrachien, Ragab and Giordano, 2006). Soil degradation is a paramount concept encompassing a range of processes such as, erosion caused by water, wind and tillage, decline in organic carbon content, compaction, salinization and sodification, contamination by heavy metals or pesticides, the excess presence of nitrates and phosphates, and decline in biodiversity.

Wrachien, Ragab and Giordano (2006) identified three major driving forces behind desertification in the Mediterranean region: first, a change in agriculture from extensive systems based on grazing and dryland wheat to intensive agriculture based on tree crops, horticulture and irrigation; second, social changes accompanied by an improvement in the standard of living and migration from the countryside to the city or overseas; third, the growth of tourism and the littoralization of the Mediterranean economy. Chisci (1993) adds that the move of agricultural systems away from extensive types of livestock-grazing towards specialized-mechanized hill farming has added to the modification of morpho-structural and infrastructural features of the landscape: soil disturbance by ploughing up-and-down contour lines, removal of vegetative soil cover and/or hedgerows, increased field size and abandonment of terraces, late sowing of winter cereals, overstocking, poor crop management and inappropriate use of heavy machinery, in agricultural and forestry practices or during construction works. In addition, land abandonment owing to migration or economic marginalization of previously cultivated fields and farms has altered the landscape and has increased the risk of forest and pasture fire. Land erosion as part of the wider land degradation processes has important on-site and off-site effects. Soil erosion is responsible for on-site loss of organic matter, soil structure degradation, soil surface compaction, reduction of water penetration, supply reduction to the water table, surface erosion, nutrient removal, increase of coarse elements, rill and gully generation, plant uprooting and reduction of soil productivity. Off-site effects are equally if not more important than on-site effects. Eroded soils contribute to higher runoff rates and sedimentation, with a risk of floods and the consequent damage to infrastructures. Reduced water retention capacity as a result of lower infiltration rates is associated with many issues, especially water management through aquifers.

Panagos *et al.* (2012) have modelled soil erodibility in Europe by utilizing the K-factor in the commonly used soil erosion model USLE (Universal Soil Loss Equation). The K-factor is related to crucial soil factors triggering erosion (organic matter content, soil texture, soil structure, permeability). Panagos *et al.* (2012) calculated soil erodibility using measured soil data, collected during the 2009 Land Use and Cover Area frame Survey (LUCAS) soil survey campaign across the member states of the European Union. Figure 8 shows the soil erodibility in Europe where it is evident that southern Europe and the

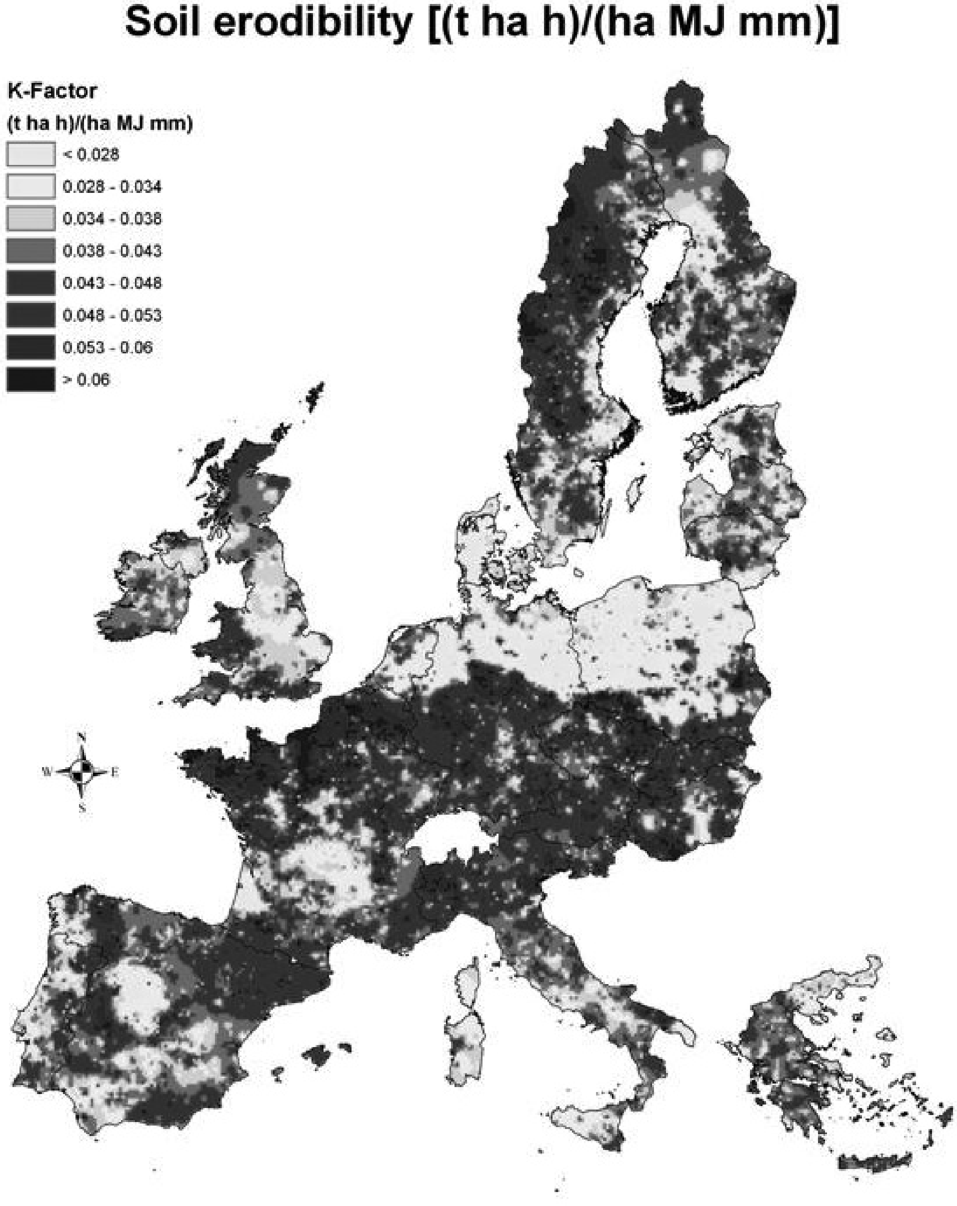


**Figure 8. Soil erodibility in Europe**

*Source*: Panagos *et al.* (2012). Source of map: http://eusoils.jrc.ec.europa.eu/library/themes/erosion/Erodibility/, last accessed 22 February 2012.

Mediterranean region suffer from high erosion. It was recognized early on that soil erosion is of considerable importance for southern Europe and the Mediterranean, and for this reason the European Commission launched a first attempt to map natural resources and soil erosion risks in Mediterranean Europe (CORINE, 1992). Since then, data availability has improved and more research activities such as the Pan-European Soil Erosion Risk

Assessment Project (PESERA) were supported. The Commission of the EU reported that: "An estimated 115 million hectares or 12 percent of Europe's total land area are subject to water erosion, and 42 million hectares are affected by wind erosion and that an estimated 45 percent of European soils have low organic matter content, principally in southern Europe but also in areas of France, the United Kingdom and Germany" (European Commission, 2006a). The Mediterranean region is particularly prone to erosion as it is subject to long dry periods, followed by heavy bursts of erosive rain, falling on fragile soils on steep slopes. It is estimated that, at present, water erosion in the Mediterranean region could result in the loss of 20/40 tonnes/ha of soil after a single cloudburst, and in extreme cases the soil loss could be over 100 tonnes/ha. Soil erosion and the risk to desertification in southern Europe and the Mediterranean are closely related to the forecasted increase of forest and wilderness fires and the consequent canopy removal, especially on high slope areas.

According to the United Nations Convention to Combat Desertification (UNCCD), the North Africa subregion represents the entire range of the aridity index. The major issues of concern in the subregion are rainfall variability, recurrent droughts, and possible impacts of climate change. All land-use categories in North Africa are subject to land degradation processes, through more than three decades, owing to several pressures including: rapid population growth, climatic stresses, human mismanagement practices, and inappropriate agricultural policies (UNCCD). Land degradation processes are varied and diversified under both rainfed and irrigated conditions, range and forestlands and conducive to serious productivity losses, reduction in return from capital investment, lower income of rural households, spread of poverty and increased rural to urban migration. A combination of some of these threats will increase under climate change and can ultimately lead areas of the Mediterranean to desertification, i.e. land degradation in arid, semi-arid and dry subhumid areas resulting from climate variations and human activity (Wrachien, Ragab and Giordano, 2006). Global climate change could have significant impacts on soil erosion, but these impacts have received little research attention since they involve complex interactions between multiple factors governing erosion rates (Kundzewicz *et al*., 2007). Thus, climate change, with its short- and long-term variation and gradual changes in temperature and precipitation, will apply an additional stress on rates of land degradation through:

- changes in the length of days and/or seasons;
- recurrence of droughts, floods and other extreme climatic events;
- changes in temperature and precipitation, which in turn reduce vegetation cover, water resource availability and soil quality; and
- changes in land-use practices, such as conversion of lands, pollution and depletion of soil nutrients. (UNCCD website accessed at: http://www.unccd.int).

Research suggests that climate change-induced land degradation will vary geographically. The underlying adaptive capacity of both the ecosystem and communities will determine the extent and direction of impacts. Regions that are already constrained by issues such as land quality, poverty, technology constraints and other socio-economic constraints are likely to be more adversely affected. Concern is particularly focused on regions where increased rates of land degradation as a result of climate change are likely to decrease livelihood opportunities and worsen rural poverty. Nunes *et al.* (2009) argue that "the impacts of climate change on storm runoff and erosion in Mediterranean watersheds are difficult to assess due to the expected increase in storm frequency coupled with a decrease in total rainfall and soil moisture, added to positive or negative changes to different types of vegetation cover". Nunes *et al.* (2009) analysed the sensitivity of runoff and erosion to incremental degrees of change (from −20 to + 20 percent) to storm rainfall, pre-storm soil moisture and vegetation cover, in two Mediterranean watersheds. The authors underline the high sensitivity of storm runoff and peak runoff rates to changes in storm rainfall (2.2 percent per 1 percent change) and to soil water content (−1.2 percent per 1 percent change). However, at a catchment level, their results showed a greater sensitivity than those within-watershed. In addition, the authors conclude that "… decreasing soil moisture levels caused by climate change could be sufficient to offset the impact of greater storm intensity in Mediterranean watersheds".

Finally, it should be acknowledged that soils play an important role in carbon sequestration, and thus processes that destruct soil structure such as erosion and desertification may have serious impacts on this process. Lal (2004) argues that soil erosion and deposition are responsible for losses in the soil organic carbon (SOC). The SOC is preferentially removed by wind- and water-borne sediments through erosional processes. Lal (2004) argues that although some of the SOC-enriched sediments are redistributed over the landscape, others are deposited in depressional sites, and some are carried into the aquatic ecosystems. The carbon emitted into the atmosphere either as $CO_2$ by mineralization or as $CH_4$ by methanogenesis may be as high as 0.8 to 1.2 Gt per year globally, while erosion-induced deposition and burial may be responsible for 0.4 to 0.6 Gt per year. Quantification of emission versus burial of carbon is a high priority. However, effective soil erosion control is essential to sustainable use of agricultural soils and improving environment quality.

## 4. MEDITERRANEAN FORESTS UNDER CLIMATE CHANGE

Saket and Hayder (2010) argue that "climate change is expected to have significant, if not severe, impacts on Mediterranean ecosystems". Forecasted climate change and the occurrence of extreme events in southeast Europe and the Mediterranean region are expected to have significant impacts on forests and forest ecosystems in general. Lindner *et al.* (2008) recount the likely impacts of climate change on Mediterranean forest ecosystems and especially on wood production, non-wood forests products, carbon sequestration and biodiversity. The importance of this issue has mobilized not only the European Union but also FAO and individual governments. In December 2009, the German Federal Ministry for Economic Cooperation and Development approved the regional project "Adapting forest policy conditions to climate change in the Middle East and North Africa (MENA) region" with the aim of improving the political framework conditions for the sustainable management of forest ecosystems in order to preserve forest-related environmental services in the context of climate change in selected countries of the MENA region that have sizable forest areas (Morocco, Algeria, Tunisia, Turkey, Syrian Arab Republic and Lebanon).

Keenan *et al.* (2011) assess the potential future of current forest stands in the Mediterranean basin, where important future climatic changes are expected. $CO_2$ fertilization through projected increased atmospheric $CO_2$ concentrations is shown to increase forest productivity in a mechanistic process-based model framework, despite increased drought stress. This increase is up to three times that of the non-$CO_2$ fertilization scenario by the period 2050–2080. In a niche-based model framework, projections of reduced habitat suitability are drawn for the same period. This highlights the importance of introducing aspects of plant biogeochemistry into current niche-based models for a realistic projection of future species distributions. The authors conclude that the future of current Mediterranean forest stands is highly uncertain and suggest that a new synergy between niche- and process-based models is urgently needed in order to improve our predictive ability.

De Dios *et al.* (2007) reviewed more than 60 studies addressing the effects of global warming on forest ecosystems and drew a long list of possible impacts that can be categorized under three headings: forest health, species migration and displacements, and fire erosion and desertification. Sturrock *et al.* (2011) provided an extensive review of the impact of climate change on forest diseases at a global scale and highlighted the relationships between climate variables and several forest diseases, as well as the processes by which climate, host and pathogen interactions are responding or might respond to climate change. De Dios *et al.* (2007) argued that climate change, by worsening climate conditions in the Mediterranean, will trigger two processes that will impact forest health. First, trees will be weakened by unfavourable environmental conditions in increasingly larger proportion and will become susceptible to pathogens. Thus, many trees will die, reducing the standing biomass. Second, the pathogen population will build up to the point of threatening trees that perhaps could resist a light attack but not a heavy infestation. The periods of extreme drought cause short- and medium-term loss of pine cone production, abortion of immature cones, loss of quality seeds and early cone opening. In the 2005 drought, all these factors caused the decline of the number of stored kernels in pine trees by more than 50 percent (Espelta, Arnan and Rodrigo, 2011). Scots pine (*Pinus sylvestris*) seems to be particularly sensitive to drought, suggesting that this pine species may become endangered in the Mediterranean basin especially in the relict stands of its southernmost location on isolated high mountains. Finally, there is also a risk from the invasion of non-native pathogens such as the *Bursaphelenchus xylophilus* that was found in Portugal for the first time in 1999. Sánchez-Humanes and Espelta (2011) focused on the effects of extreme drought on one of the most abundant trees in the Mediterranean, the oak (*Quercus ilex*), with rather inconclusive results. The authors found that a simple moderate decrease in precipitation (10 percent) reduced the number of productive trees by 25 percent and the number of the produced acorns by up to 50 percent. The same study also showed that traditional management practised in some of these forests to control density, such as clearing of sprouts, hardly diminishes the impact of drought on reproduction.

De Dios *et al.* (2007) suggested that “losses will probably be greatest for trees on the edges of their natural distribution where a small change will make the environment unsuitable for them” and that “some forest diseases now considered minor may become serious”. The increasing incidence of oak declines such as *Quercus ilex* L. (holm oak) may be a vivid example of climate change implications on forest health. It is hypothesized that the decline in holm oak in the Iberian Peninsula is due to *Phytophtora cinnamomi*, which requires wet soil conditions that are not met in this area. However, in the last few decades, floods have occurred more frequently, creating favourable conditions for the pathogen in these forests (De Luís *et al.*, 2001). These floods have been followed by drought events that have weakened the trees and made them more susceptible to the pathogen, resulting in higher mortality than ever before. A number of pathogens including *Ceratocysits ulmi* (Buism.) Moreau (Dutch-elm disease), *Hypoxylon mediterraneum* (De Not.) J. H. Miller (Hypoxylon canker) are likely to cause damage in southern Europe while *Heterobasidion annosum* (Fr.:Fr.) Bref. (Heterobasidion root rot) is likely to cause increasing damage in northern latitudes. The pine tent caterpillar (*Thaumetopoea pytiocampa*) may have increased effects on *P. sylvestris* or *P. halepensis* causing decreased seed production, seed mass and seedling survival. In the case of pine (*P. halepensis*), results show a direct relationship between extreme drought and loss of fertility of the pines.

As concerns species migration and displacement, early models forecasted shifts in forest biomes or ecosystems as intact entities and as a response to climate change. These models are no longer useful because plant communities are the result of interactions among organisms as well as among organisms with their abiotic environment, and thus climate change will not shift entire ecosystems but will alter species assemblage composition. Larger-scale effects of climate change include the biogeography of species with the most vulnerable being the forests of species grown at the margins of their geographic expansion in respect to soil moisture and temperature (Royce and Barbour, 2001). Regato (2008) argued that “the high heterogeneity of the Mediterranean landscapes, where a varied range of environmental conditions and a large ensemble of tree species and habitats with different optimum bioclimatic requirements are found within a very small area, may help considerably reduce dispersal distance requirements”. Research using simulations suggests that deciduous trees, such as *F. sylvatica* or *Quercus petraea* L. (sessile oak), would invade today’s subalpine belt displacing conifers that may migrate into today’s alpine zone if soils are suitable for forest growth. Aleppo pine (*P. halepensis*) may be a likely substitute for *Q. ilex* in the short term because it is more resistant to drought, although its populations are also expected to diminish under long-term drought conditions (Camara-Obregon 1998; Lloret and Siscart, 1995 cited in de Dios *et al.*, 2007). In mountain regions, certain species and communities could disappear completely because the upward displacement of species living close to the upper reaches of mountains will be constrained by the lack of any suitable habitat. This will affect agro-forest systems in mountainous areas. Early evidence of this may be seen in the southern slopes of the Pyrenees where the mountain pine is undergoing serious decline (de Dios *et al.*, 2007). In addition, with sea level rise, depending on the scenario, from 0.25 m to 1 m (Airoldi and Beck, 2007), there may be profound impacts on coastal ecosystems including coastal forests and coastal grasslands (Nicholls and Hoozemans, 1996).

However, the most serious effect of climate change, and especially of increased temperatures and summer droughts, is expected to be the risk of forest fires. Depending on the scenario, it is expected that, in southern Europe, climate change will increase forest fires by 10–20 percent (Carvahlo *et al.*, 2010). Giannakopoulos *et al.* (2009) show that, under a climate change scenario of a rise in temperature by 2 °C, forest fire risk increases considerably. This increase is higher during the summer, with the maximum in August and in the North Mediterranean inland while the Balkans, Maghreb, North Adriatic, central Spain and Turkey seem to be the most vulnerable regions; south of France is as strongly affected as Spain, but only in August and September, while the southeast Mediterranean (from Lebanon to Libya) sees no particular increase or decrease. Giannakopoulos *et al.* (2009) argue that this increase in fire risk is translated to 2–6 additional weeks of fire risk (i.e. more than a month) over all land areas with a significant proportion of this increase in fire risk being extreme fire risk. Forest fires on dry compacted soils expose the soil to high intensity storms resulting to soil erosion and nutrient loss and the consequent shift from forest cover to shrub land and bush land, especially in areas close to sub-desert zones and steppes. Forest fires will increase water runoff and contribute to the occurrence of extreme phenomena such as floods and landslides.

Giannakopoulos *et al.* (2009) used the Canadian Fire Weather Index (FWI) system to model fire risk under climate change conditions in the Mediterranean region. The Canadian FWI consists of six components that account for the effects of fuel moisture and wind on fire behaviour. The three components accounting for fuel moisture and wind include numeric ratings of the moisture content of litter and other fine fuels, the average moisture content of loosely compacted organic layers of moderate depth and the average moisture content of deep, compact organic layers. The three components accounting for fire behaviour include indices for the rate of fire spread, the fuel available for combustion, and the frontal fire intensity. The values of the FWI rise as the fire danger increases. Fire risk is low for FWI up to 15, and increases more rapidly with FWI more than 15. Giannakopoulos *et al.* (2005; 2009) selected a threshold of FWI more than 30 as a measure of increased fire risk, calculated the monthly changes of average FWI from May untill October between the future and the control period and found that: “The increase is higher during the summer, with the maximum increase in August in the North Mediterranean inland”, “Balkans, Maghreb, North Adriatic, central Spain, and Turkey seem to be the most vulnerable regions”, the “South of France is as strongly affected as Spain, but only in August and September”and the “southeast Mediterranean (from Lebanon to Libya) sees no particular increase or decrease”. In general, the increase in the mean FWI is translated into (Giannakopoulos *et al.*, 2005; 2009):

- Two to six additional weeks of fire risk are expected everywhere except for Provence, southern Italy/Sardinia, northern Tunisia and Libya where one week more is foreseen, and Egypt and the Middle East coast where no increase is foreseen. A greater increase of up to 6–7 weeks is expected inland (central western Iberian Peninsula, the Atlas mountains and plateaus in North Africa, large parts of Serbia, Bosnia-Herzegovina and Montenegro in the Balkans, and northeastern Italy), where a significant proportion of this increase will actually be related to extreme fire risk. A smaller increase is expected in the coastal areas with almost no change in extreme fire risk, except for the Iberian Peninsula, Morocco, northern Italy and the eastern Adriatic coast.
- A significant proportion of this increase in fire risk is actually extreme fire risk (FWI more than 30).
- The maximum increase in fire risk will occur in July and August, especially in the central part of the Iberian Peninsula, northern Italy, the Balkans and central Anatolia.

Outside the summer months, fire risk increase is expected in May and October in the Iberian Peninsula, Morocco and Algeria, and only in May in southeastern Turkey and the Syrian Arab Republic.

- Significant increase in the number of days with fire risk (1–4 weeks), but not in the number of extreme fire risks for the South of France, and coastal areas of the rest of Mediterranean region.

Trigo (2012) argues that the last decade has been characterized by frequent heatwaves within the Mediterranean-European region, which have triggered a large number of wildfires, such as in Portugal (2003, 2005), Spain (2006), Italy and Greece (2007) and, more recently, Ukraine and the Russian Federation (2010). The 2003 heat wave was characterized by new all-time record values of maximum and minimum temperatures over Portugal in early August. These extreme temperatures and the associated low humidity values triggered the most devastating sequence of large fires ever registered in Portugal, with an estimated total burnt area of about 450 000 ha (Trigo *et al.,* 2006). In Israel, the frequency, intensity and extent of the fires would increase owing to the prolongation of droughts, increase in water evaporation and an increased frequency of intense heat waves. At a very moderate and conservative warming of 1.5 °C by the year 2100, models predict the desert to expand northward by 300 to 500 km. Mediterranean ecosystems, such as the one occurring in the Carmel Mountains, would disappear from Israel. For example, present day forest fires in the Carmel mountain range in northern Israel were preceded by eight months of drought and occurred during a heatwave with temperatures around 30 ºC. Normally, first rainfall should have come in September or October, and the maximal daily temperature at this time of year should be around 15–20 ºC. Lindner *et al.* (2008) argued that fire protection will be mainly important in the Mediterranean and temperate continental forests of Europe with different forest types requiring specific fire-management policies. They list a number of adaptation measures to enhance fire protection or to reduce risks of fire, including modification of forest structure (e.g. tree spacing and density, regulation of age class structure), removing standing dead trees and coarse woody debris on the forest floor, changing species composition, creating a mosaic of forest types including species with reduced flammability, and fuel management through thinning and biomass removals, grazing or the use of prescribed burning.

It is important to note that forest fires are associated with soil erosion, desertification and carbon sequestration owing to the significant effects that fires exercise on soils. In the Mediterranean region, fire is largely regarded as a major driving force of geomorphological processes, vegetation dynamics and landscape evolution. Additionally, wildfires impact a variety of soil properties. The magnitude, rate and type of most fire-affected processes are determined by the complex interactions between the physical, chemical and biological properties of the soil, as well as the characteristics of the fire itself. For example, following low to moderate fires, properties such as aggregate stability, pore size distribution and water repellency, together with the effects of ash and clogging of macropores, increase runoff and soil loss. However, following severe fires, the presence of wettable ash and the loss of surface water repellency may increase infiltration rates and accordingly decrease runoff and soil loss. Results from previous studies indicate that the most common chemical characteristics of fire-affected soils are organic matter, carbon, NPK minerals, cation exchange capacity, pH and buffering ability (Wittenberg, 2012). Certini (2005) has reviewed the effect of forest fires on soils and argues that low to moderate fires have little or no negative impacts (they rather eliminate undesired competitor species and increase pH and nutrient availability), but the enhancement of hydrophobicity can render the soil less able to soak up water and more prone to erosion. Severe fires can cause significant removal of organic matter, deterioration of both structure and porosity, considerable loss of nutrients through volatilization, ash entrapment in smoke columns, leaching and erosion, and marked alteration of both quantity and specific composition of microbial and soil-dwelling invertebrate communities (Lindner *et al.,* 2008).

## 5. RESILIENCE TO CLIMATE CHANGE

A sharp distinction should be made between mitigation and resilience. Mitigation refers to actions aiming at decreasing potential effects of global warming and consequent climate change. Resilience refers to actions aiming at building tolerance against the effects of global warming. Mitigation technologies and practices fall under three broad categories including reducing emissions, enhancing removals and avoiding or displacing emissions (Smith *et al.*, 2007). Bockel (2009) suggested that in agriculture, climate change adaptation refers to actions aiming to improve the resilience of the sector and reduce its vulnerability to changing climate. He also argues that, especially in agriculture, it is difficult to differentiate between mitigation and resilience measures, as these, very often, come together; indicatively, enriched carbon soils are resilient to drought and erosion, while carbon-fixing mitigation can induce rural income diversification, and thus strengthen economic resilience, especially in the case of poor rural households. However, the focus of this section is on resilience actions preparing agriculture and forestry to tolerate foreseen climate changes in southern Europe and the Mediterranean region. Examining resilience actions is a crucial step because, even if mitigation measures show signs of reducing greenhouse gas emissions, they will not be sufficient either to capture or to halt changes in temperature and precipitation rates. Thus, building resilience should be part of the strategic policy response to climate change (Iglesias, Quiroga and Diz, 2011; Iglesias *et al.*, 2011b).

In a recent study by the Institute for European Environmental Policy (Cooper and Arblaster, 2007) adaptation actions are distinguished in a two-fold manner. First, three broad categories are specified, namely behavioural, technological or management-based. For example, climate change will decrease water supply (lower precipitation) and increase demand (high temperatures and droughts) for irrigation water in the Mediterranean region, and thus methods of adapting to low water availability will become increasingly important. Such methods will require technological as well as managerial and behavioural solutions. From the technological point of view, a shift to water conservation on-farm may lead to the widespread adoption of drip irrigation techniques that also may imply a shift to liquid irrigation and new methods of applying plant protection substances. From a managerial and behavioural point of view, a shift to water conservation practices may include the adoption of drought-resistant crops, the adoption of water-saving cropping methods such as mulching, minimum tillage and maintenance of cover crops, a change in planting dates and cultivars, and even a shift to cropping zones by altitude and latitude. Other adaptations, largely unforeseen today, may be related to changing pest behaviour or to changing the demand for nitrogen-related fertilization owing to concentrations of atmospheric $CO_2$ that will increase nitrogen uptake by crops. Besides traditional plant breeding for producing new crop varieties, actions supporting resilience may include the adoption of farm management techniques for producing more nitrogen by leguminous crops and animal feeds, for example, roots, cereals and legume rich leys, in rotation (Kundzewicz *et al.*, 2007). Second, adaptation measures for agriculture are distinguished between short- and long-term options, depending on the magnitude of the change requited. Shorter-term agricultural adaptations include water conservation, changes in planting dates and cultivars, changes in external inputs and changes in animal housing systems. Longer-term adaptations include land-use changes, namely crop substitution, mostly induced by water scarcity and crop breeding, through the utilization of conventional genetics and biotechnology.

Giannakopoulos *et al.* (2009), whose climate change models for the Mediterranean region are extensively presented in section 2, examined the effects of two farm level climate change resilience strategies. They introduced in their crop yield simulations two adaptation measures that aim to cope with the impacts of global change, namely early sowing and shortening of growing season. Figure 9 shows that early sowing date (the grey bars), because it is associated with the shortening of the growing season (due to high temperatures), may reduce the negative impacts of climate change or even enhance positive impacts, allowing crops to escape higher temperature and water stress. For example, in the case of C3 summer crops in Egypt, early sowing is shown to produce significant positive effects out of slightly negative climate change effects. The use of longer growing cycle cultivars is a worthy adaptation practice because higher temperatures trigger increase of development rate. For example, the negative climate effects on legumes are reverted to positive for Tunisia, Libya and Greece, if longer growing cycles are adopted. Both adaptation practices, however, would require additional water for irrigation which re-connects farming practices to a wider water management strategy under climate change. The authors noted that, for example, the effective use of long-cycle cultivars can demand 25–40 percent more water, which may not be available or may not be a cost-effective measure under future climate change scenarios.

At the farm level, the adoption of resilience measures is a complicated issue and should not be regarded, by any means, as a panacea to climate change concerns. Important issues are related to the adoption of resilience measures at farm level. First is the identification of factors inhibiting or constraining the adoption of resilience measures. Second is the examination of whether action at farm level is adequate or should it be coupled and coordinated by actions at higher geographical and organizational levels. There are factors, exogenous and endogenous to the farm, that affect the intensity and time of the adoption of resilience measures at farm level. Factors related to the availability of innovations in technology and sciences (e.g. the availability of improved drought-resistant varieties) are purely exogenous to the farm. Factors related to farm practices are endogenous to the farm and depend on the learning curve of farmers in relation to climate change incidents.

As Meza and Silva (2009) have shown for Chile, farmers learn from past experience and dynamically adapt production to climate change. However, the form of the learning curve

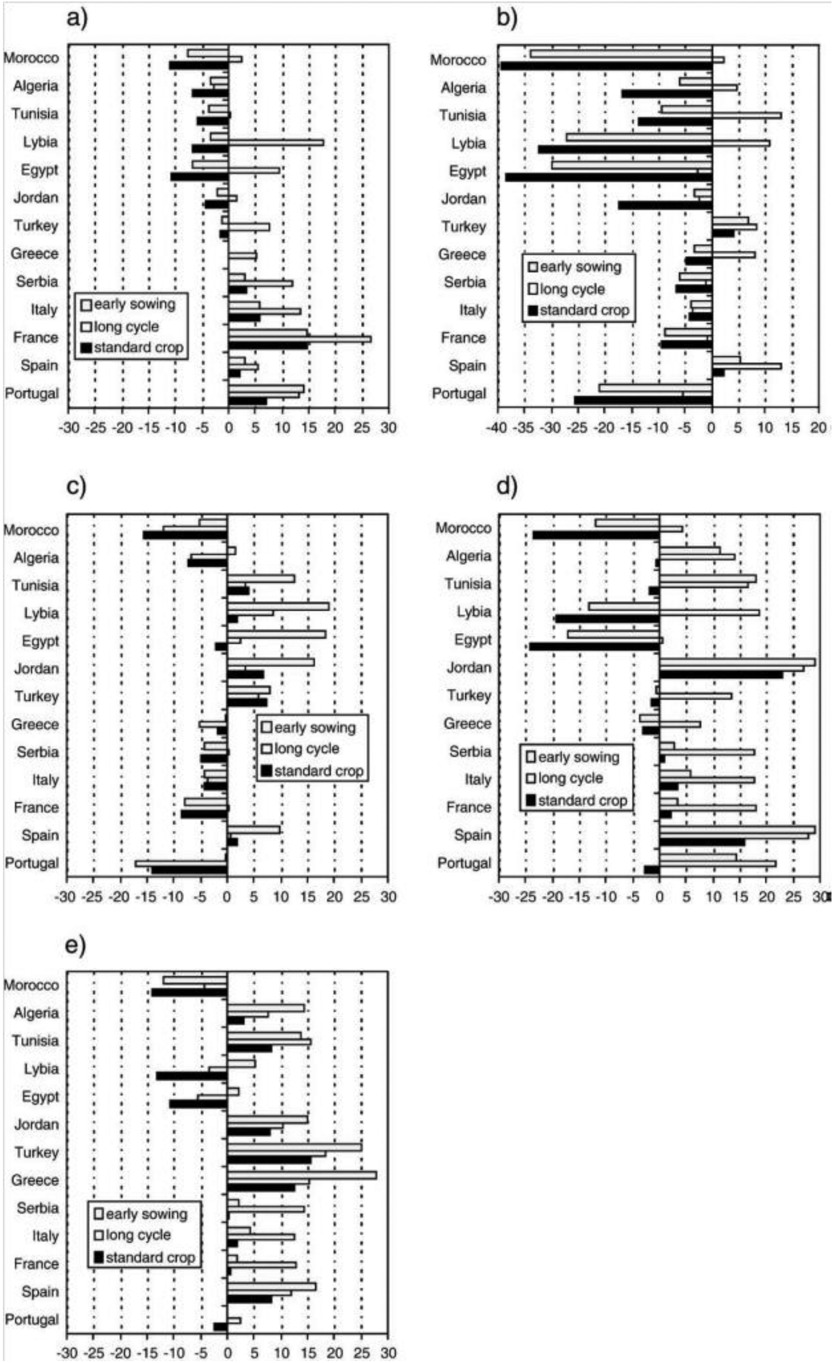


**Figure 9. Impact of different crop adaptation options on crop responses under climate change for: (a) C4 summer crop, (b) legumes, (c) C3 summer crop, (d) tuber crops, (e) cereals**

The changes reported in the figures are expressed as percent and obtained as differences between the mean yields of the two futures scenarios and the present yields.

*Source*: Figure 10 in Giannakopoulos *et al.,* (2009).

differs from farmer to farmer and depends on the capacity and skills that farmers have to assimilate changes. In general, the likely success of resilience measures at farm or sectoral level depends on a range of socio-economic factors including farm characteristics, such as production type, size of the farm, level of intensity, the diversity of cropping and livestock systems, the presence of other income sources apart from agriculture, access to relevant information, skills and knowledge about climate trends and adaptive solutions, the role played by advisory services in facilitating adaptation, the general socio-economic situation (with farmers with limited resources or living in remote rural areas being most vulnerable) and access to available technology and infrastructure capacity (European Commission, 2009a).

The adoption of resilience measures at farm level should not be left uncoordinated at local and regional levels because not all resilience measures are internally coherent and always consistent with wider, non- agricultural objectives at regional level. One example of internal incoherency was pointed out above, where the adoption of long-cycle cultivars increases demand for water. As such, a resilience measure adds stress to water resources, the existence of which forms the basis for a range of other resilience measures. In addition, and despite their potential to maintain the productive capacity of agriculture, several adaptation measures affect biodiversity, often negatively. Indicatively, in the Mediterranean region, irrigation is a key adaptation strategy, often associated with significantly negative biodiversity impacts. Increased irrigation may threaten several protected sites, especially RAMSAR Convention sites, by reducing water directed to these sites below the minimum ecological allotment or by directing to them water that will be increasingly polluted from fertilizers. On the other hand, the adoption of resilience measures at farm level, if appropriately coordinated, may maximize the positive impacts of the soil conservation strategies against soil erosion and desertification. For example, conservation tillage, which is the practice of leaving some or all of the previous season’s crop residues on the soil surface, is a water conservation measure because it increases moisture by reducing evaporation and increases infiltration of rainwater into the soil. At the same time, it leaves a protective cover on the soil against extremely heavy rains or other extreme events (wind, drought, etc.) and thus protects the soil against water and wind erosion. All the aforementioned concerns raise the issue of a carefully designed resilience strategy at regional and even national levels.

Indeed, many researchers argue that there are limits to the effectiveness of simple farm-level resilience measures under more severe climate changes, which may call for more systemic changes in resource allocation (Howden *et al.*, 2007). For example, Bockel (2009) argues for a “country focus”, integrating adaptation and mitigation into national sectoral policies and strategies, and for an “implementation focus” through the formulation and scaling up of projects and programmes. A “country focus” should aim at the consolidation of the resilience of cropping systems (through crop type diversification, development of more tolerant varieties, encouragement of crop rotations and crop systems with low reliance on fertilizers and pesticides), of watersheds and infrastructure to natural disasters (through reforesting degraded areas, maintaining water drain channels and developing local watershed/land-use plans) and of vulnerable populations to shocks (through the activation of national risk management systems including monitoring, forecasting and warning systems, as well as exposure-minimizing infrastructures, insurance and emergency response capacity). A wide range of public services and support policies is advocated in order to facilitate these agricultural resilience policy targets. In turn, an "implementation focus" could involve the *ex ante* project and programme appraisal of carbon balance, the enhancement of the poverty reduction potential, food security and sustainable development through payments for environmental services and the strengthening of productive, social and environmental safety nets.

Further, it has been pointed out that the choice and effectiveness of resilience measures vary owing to differentiation of and interactions between climate, environmental, cultural, institutional and economic factors. Thus, in a wider context, the design and application of measures can be "placed" into a wider strategic framework influenced by economic, political, institutional and social factors, as well as by interactions with the objectives of a rather broad set of policies (Cooper and Arblaster, 2007). Such a perspective has raised discussions on several issues. These include the links between small-scale/short-term responses that are often popular with farmers, and large-scale/longer-term options, which are associated with higher uncertainty at the micro level but can be more reliably projected with existing tools and thus have a potential to facilitate concrete policy decisions. Also, complex contexts and interactions have raised arguments for closer links between adaptation policies and other public intervention domains associated with sustainable development, and even for the mainstreaming of adaptation into planning for a wide range of policies. Other issues raised include the effective integration of mitigation and adaptation, the provision of information to governments and industries on investment decisions associated with efforts to combat climate change, the rewarding of early adopters and a focus on climate risk management. In a wider sense, a change in policy design and implementation has been advocated in order to improve adaptation effectiveness and adoption; this could involve deliberate, dynamic local, regional, national and international responses in a range of activities including infrastructures, community and institutional capacity-building and, generally, modifications to the decision-making environment associated with management-level adaptation activities (Howden *et al.*, 2007).

In a European Union (EU) context, the well-established agricultural policy has facilitated the entering of climate change in the lexicon of the Common Agricultural Policy (CAP). Initially, the European Commission granted incentives for growing energy crops. Then, it facilitated the building of resilience measures at sectoral level, beyond the aforementioned farm-level measures (European Commission, 2009a). In this context, it was argued that sector-wide planning and advice are necessary, because some of the measures for adjusting to new climatic conditions are likely to be costly and may need significant investments by farmers, thus indirectly raising an issue of disproportionate resilience costs. Examples of sectoral-level adaptation actions include the identification of vulnerable areas and assessment of needs and opportunities for changing crops and varieties in response to climate trends; support to agricultural research and to experimental production aiming at crop selection and development of varieties best suited to new conditions; investment in improved efficiency of irrigation infrastructure and water-use technologies; building adaptive capacity by awareness-raising and provision of salient information and advice on farm management; developing irrigation plans based on thorough assessments of their impacts, future water availability and water needs of different users, taking account of the balance between demand and supply; developing risk and crisis management instruments to cope with the economic consequences of climate-driven events.

Through the radical 2003 reform of the CAP and the 2008 “Health Check” agreement (European Commission, 2009b), more emphasis was given to sustainable development of EU agriculture from both an economic and environmental perspective. In terms of income support, the decoupling of agricultural support from production factors allowed farmers to orient production decisions according (also) to biophysical conditions affected by climate change. Also, cross-compliance requirements (extended by the “Health Check”) contribute to the sustainable use of resources and adaptation, while Farm Advisory Systems and risk management tools can also be effective tools for sustaining adaptation in EU farms. CAP support to farmers’ adaptation efforts is also granted through the EU Rural Development Policy (RDP). In the case of the 2007–2013 programming period, both strategic and regulatory documents (European Commission, 2005; 2006b) contain explicit references to EU objectives for climate change mitigation. RDP measures with a potential to sustain adaptation to climate change include farm modernization, restoring agricultural production potential, improvement and development of infrastructure, adding value to agricultural and forestry products, agri-environmental schemes, support to LFAs and investment in human capital. Furthermore, since 2009, the implementation of the “Health Check” agreement included climate change mitigation and adaptation, renewable energy, water management and biodiversity among “New Challenges for European Agriculture” and directed additional financial support towards RDP measures pursuing such priorities.

The CAP post-2013 legal proposals and, more specifically, the proposal for the post-2013 RDP Regulation (European Commission, 2011) seems to signal an even higher focus of the CAP towards climate change adaptation and mitigation. The proposal specifies climate change adaptation and mitigation as a cross- cutting objective of rural policy, and defines the support of the shift towards a low carbon and climate resilient economy in agriculture, food and forestry sectors, as one of six EU RDP priorities, linking it with the following thematic programming objectives:

- increasing efficiency in water use by agriculture;
- increasing efficiency in energy use in agriculture and food processing;
- facilitating the supply and use of renewable sources of energy, of byproducts, wastes, residues and other non-food raw material for purposes of the bio-economy;
- reducing nitrous oxide and methane emissions from agriculture;
- fostering carbon sequestration in agriculture and forestry.

Further, it emphasizes the role of agri-environmental payments (which are now termed as agri- environment-climate payments) in encouraging farmers to introduce or continue to apply agricultural practices contributing to climate change mitigation and adaptation, and introduces a “new” risk management measure to assist farmers in addressing the most common risks, including climate change. It also defines that “Member States have to allocate at least 25 percent of their total RDP spending for climate change mitigation and adaptation and land management, through the agri-environment-climate, organic farming and payments to areas facing natural or other specific constraints measures". Despite the rather obvious higher attention of the post-2013 RDP to climate change adaptation and mitigation action, one cannot ignore that past criticism on the lack of dedicated measures responding to climate change (Cooper and Arblaster, 2007) is perhaps still valid. Also, first evidence on 2007–2013 financial allocations to the climate change "New Challenge" does not indicate any considerable utilization of such an option in Southern European Member States, which in turn seem to have followed past practices (Iglesias *et al.*, 2007) and remain quite active in utilizing RDP resources for water management.

In Northern Africa, a recent report (OSS/UNEP, 2010) includes a compilation of existing and planned adaptation and mitigation measures that have occurred or will occur in North Africa. In the case of the rural land-use sector (agriculture/forestry), there seem to be rather few examples of planned adaptation measures.

There are some ad hoc examples of farmers and voluntary initiatives to improve farming practices, mostly driven by sustainable development policies at the local or regional levels. According to the report, reasons behind low uptake include uncertain information on climate change impacts and limited representation of farmers in decision-making processes. Both these factors undermine incentives to promote climate change adaptation. Of course, there are some success stories, including cooperative action on the restoration of degraded rangelands in Morocco and community-based organizations and action plans to improve land management in the degradation-prone dry lands of the Masreq and Maghreb countries. Taking account of the extrinsic link between development and adaptation, it is perhaps not surprising that the report emphasizes the importance of capacity building, synergy enhancement (i.e. integration of adaptation into development strategies and plans) and technology transfer. Especially for agriculture, a fundamental role for government in promoting resilience is advocated, as a means to improve information on projected climate change effects – information needed by farmers to design and build resilient farming systems and fill extension and educational gaps, which are quite common amongst the farming community.

De Dios *et al.* (2007) suggest a series of strategies for mitigating climate change impacts for the forest environment in the Mediterranean. The first is the "Conservation Management Strategy", which aims to prevent emissions and conserve current forest carbon pools through diminishing deforestation, increasing rotation period, reducing thinning intensity and restricting several harvesting activities. The second approach is the "Storage Management Strategy", a mitigation strategy aiming at increasing the amount of carbon stored in vegetation and soil. The third is the "Substitution Management Strategy", aiming at maximizing the time carbon is sequestered as wood. These strategies, although with a view to mitigating climate change impacts, include many adaptation measures. In general, for both agriculture and forestry, it is argued that in regions where adaptive capacity is high, negative climate change impacts will be dampened resulting in lower levels of risk. This may be the case of the Mediterranean region of Europe or Australia (Iglesias *et al.*, 2011a).

Taking into account the specificity and diversity of the aforementioned socio-economic factors in the Mediterranean basin, together with the fact that this region of the world is considered to be a climatic change hotspot, building a resilience strategy is a priority, "no regret" action. The prime aim of such a strategy should be to avoid the amplification of regional differences and the exacerbation of economic disparities between north-central and south European rural areas as well as among rural areas within the Mediterranean area.

## 6. SUMMARY AND CONCLUSIONS

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and which persists for an extended period, typically decades or longer. Climate change refers to present and future changes in climate conditions. Climate changes are more frequently reflected by increasing average temperature, changes in precipitation and changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events.

The Mediterranean region presents a wide variability in climate change projections but the collective picture is one of substantial drying and warming. Especially in the warm season, precipitation decrease may exceed –25 to –30 percent and warming may exceed 4–50 °C (Giorgi and Lionello, 2008). Extreme events in the Mediterranean region are related to droughts and floods and the likely occurrence of both, i.e. extreme precipitation events after prolonged droughts, which may give rise to more extreme phenomena such as deep erosion and landslides. For these reasons, the Mediterranean region is identified as one of the most prominent hotspots in future climate change projections.

Climate change is assumed to have significant effects on Mediterranean agriculture. Projected climate changes will have a direct impact on water resources and irrigation requirements, crop growth conditions, crop productivity and crop distribution, agricultural pests and diseases control and the conditions for livestock production. These impacts will generate changing land-use patterns and will trigger economy-wide effects.

In the Mediterranean parts of Europe, the declining water balance has been documented over the past 32 years. Taking into account that demand for irrigation water in southern Europe and the Mediterranean area is already very high, under drier conditions more water will be required per unit area, and peak irrigation demands are expected to rise owing to droughts and high temperatures putting crops under severe stress. In certain areas of North Africa, rainfed agriculture represents more than 90 percent of total agricultural land. In certain North Africa and east Mediterranean countries, climate change may result in surface water reductions of more than 35 percent.

Crop growth is directly affected by $CO_2$ concentrations and soil moisture that is controlled by air temperature and precipitation. In southern Europe, general decreases in yield (e.g. legumes –30 to +5 percent; sunflower –12 to +3 percent and tuber crops –14 to +7 percent by 2050) and increases in water demand (e.g. for maize +2 to +4 percent and potato +6 to +10 percent by 2050) are expected for spring-sown crops. Extreme climate events during specific crop development stages (e.g. heat stress during flowering period, rainy days during sowing time), together with higher rainfall intensity and longer dry spells, are likely to reduce the yield of summer crops. The impacts on autumn-sown crops are more geographically variable. In general, the effect of climate change on crop growth is likely to be more severe in the southern Mediterranean areas than in the northern temperate areas. In the warmer southern Mediterranean, increases in $CO_2$ may help reduce the loss in yield arising from a warmer and drier climate, but may not be able to completely recover the losses. In the cooler northeastern Mediterranean, $CO_2$ increases associated with climate change result in little net effect on most crops, provided that the increase in water demand, especially for irrigated crops, can be met. Models based on demand and supply for food conclude that countries in the south of Europe, such as Spain, Portugal and Greece, will experience very large declines in agricultural areas that are much greater than the projected European-wide changes. These land-use allocations will create a large surplus of agricultural land and grasslands. The future management of this potential surplus of land will be a challenge.

Concerning grazing, higher temperatures result in greater water consumption and more frequent heat stress, which causes declines in physical activities, including eating and grazing. Livestock production may therefore be negatively affected in the warm months of the current warmer regions of Europe. Climate change impacts will probably be minor for intensive livestock systems. On the other hand, climate change and especially higher air temperatures will create conditions suitable for the invasion of weeds, pests and diseases adapted to warmer climatic conditions. Increasing temperatures may also increase the risk of livestock diseases by supporting the dispersal of insects, enhancing the survival of viruses from one year to the next and by improving conditions for new insect vectors that are now limited by colder temperatures.

The change in land productivity brought by changing climate conditions may trigger economy-wide effects. In areas with significant productivity losses such as the Mediterranean south, and with the agriculture sector still playing a significant role in the overall economy, GDP changes are expected to be negative and significant, especially under the A2 scenario. In the Mediterranean regions, the crop supply changes are negative, which results in higher prices and no gains for the agricultural trade balance. Especially in the Mediterranean south, the agricultural trade balance under the A2 scenario may deteriorate by almost 10 to 15 percent depending on the chosen climate model (HadCM or ECHAM).

Climate change, with its short- and long-term variation and gradual changes in temperature and precipitation, will apply an additional stress on rates of land degradation through changes in the length of days and/or seasons, recurrence of droughts, floods and other extreme climatic events, changes in temperature and precipitation that in turn reduces vegetation cover, water resource availability, and soil quality and changes in land-use practices, such as conversion of land use, pollution and depletion of soil nutrients. The impacts of climate change on storm runoff and erosion in Mediterranean watersheds are difficult to assess owing to the expected increase in storm frequency coupled with a decrease in total rainfall and soil moisture, added to positive or negative changes to different types of vegetation cover. The importance of soil conservation extends beyond sustaining economic, recreational and conservation activities to their role in carbon sequestration.

Climate change is expected to have significant, if not severe, impacts on Mediterranean ecosystems. Impacts can be categorized under three headings, namely, forest health, species migration and displacements, and forest fires and their consequent erosion and desertification. Climate change, by worsening climate conditions in the Mediterranean, will weaken forest stands, making them more susceptible to pathogens and allowing the pathogen population to build up to the point of threatening trees that could otherwise resist a light attack. Species migration and displacement are very complex processes and should not be examined under a naive mechanistic shift in the biogeography of species. It is argued that the high heterogeneity of the Mediterranean landscapes, where a varied range of environmental conditions and a large ensemble of tree species and habitats with different optimum bioclimatic requirements are found within a very small area, may help considerably to reduce dispersal distance requirements.

The most serious effect of climate change and especially of increased temperatures and summer droughts on forest is expected to be the risk of forest fires. Depending on the scenario, it is expected that in southern Europe, climate change will increase forest fires by 10–20 percent. An analysis based on the Fire Weather Index shows that the increase of serious fire risk is higher during summer, with the maximum increase in August in the North Mediterranean inland. The Balkans, Maghreb, North Adriatic, central Spain and Turkey seem to be the most vulnerable regions. The South of France is as strongly affected as Spain, but only in August and September, while the southeast Mediterranean (from Lebanon to Libya) sees no particular increase or decrease. Severe fires can cause significant removal of organic matter, deterioration of both structure and porosity, considerable loss of nutrients through volatilization, ash entrapment in smoke columns, leaching and erosion, and marked alteration of both quantity and specific composition of microbial and soil-dwelling invertebrate communities, making soils more prone to erosion and desertification.

Resilience refers to actions aiming at building tolerance against the effects of global warming. At farm level, a wide range of land-use and land management practices can facilitate tolerance. The adoption of drought-resistant crops, the adoption of water-saving cropping methods such as mulching, minimum tillage and maintenance of cover crops, a change in planting dates and cultivars and even a shift to cropping zones by altitude and latitude can assist farms to adapt to the changing climate. Other adaptations, largely unforeseen today, may be related to changing pest behaviour or to changing the demand for nitrogen-related fertilization due to concentrations of atmospheric $CO_2$ that will increase nitrogen uptake by crops. Thus, besides traditional plant breeding for producing new crop varieties, actions supporting resilience may include the adoption of farm management techniques for producing more nitrogen by leguminous crops and animal feeds, for example, roots, cereals and legume rich leys, in rotation. Building tolerance at farm level depends on the farmers' learning and adaptation abilities as well as on available technological and scientific innovations.

Resilience at farm level should be coordinated and planned to avoid possible internal incoherencies among resilience measures and inconsistencies of resilience with wider rural development objectives. Certain resilience measures are contradicting water conservation objectives and create internal incoherencies.

Other resilience measures can be better coordinated in the framework of wider objectives, such as the soil and water conservation strategies or biodiversity objectives and support and promote synergies with other actions at a higher geographical level (external consistency and synergy). In an EU context, the Commission facilitated the building of resilience measures at sectoral level, beyond the farm-level measures. In this context, it was argued that sector-wide planning and advice are necessary, because some of the measures for adjusting to new climatic conditions are likely to be costly and may need significant investments by farmers, thus indirectly raising an issue of disproportionate resilience costs. In Northern Africa, there seem to be rather few examples of planned adaptation measures and some ad hoc examples of farmers and voluntary initiatives to improve farming practices, mostly driven by sustainable development policies at the local or regional levels. The reasons behind low uptake of resilience measures include uncertain information on climate change impacts and limited representation of farmers in decision-making processes. Both these factors undermine incentives to promote climate change adaptation, although some success stories in Morocco and the Masreq and Maghreb countries denote the significant hidden capabilities of the rural population.

Taking into account the specificity and diversity of the aforementioned socio-economic factors in the Mediterranean basin, together with the fact that this region of the world is considered to be a climatic change hotspot, building a resilience strategy is a priority, "no regret" action.

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# Crop–livestock production systems in the Sahel – increasing resilience for adaptation to climate change and preserving food security

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## INTRODUCTION

Rural people in the Sahelian part of Africa rely mainly on crop–livestock activities and natural resources for their livelihood and food security, and to provide food for urban populations. For centuries, these activities have been adapted to the changing environment, as spatial and time variability (seasonal and inter-annual) of rainfall have always been specific traits of this agro-ecological zone (especially in the last four decades). This zone is defined as the southern border of the Sahara desert, characterized by low and unreliable annual rainfall, usually between 200 and 600 mm/year, along a positive gradient southward and occurring mainly between June and October, defining two main climatic zones, arid and semi-arid (Figure 1). Apart from a few secondary towns and major cities (such as Dakar and Bamako), the majority of the population (more than 70 percent [FAOSTAT, 2010]) live in rural areas where they practise agriculture. Livestock farming in the Sahel has been a traditional activity for centuries based on common use of resources (water, rangelands) and regulations. Societies have built their organizations and interactions on herd, pasture and water management (Bonfiglioli, 1988; Ancey *et al.*, 2009) and various exchanges with the "outside world" (Khazanov, 1984). Grazing systems traditionally fulfil various functions through diversified and accurate use of livestock capital (sales, gifts, loans, distribution, inheritance and even thefts): organization of resource management, social recognition, collective risk management, collective food security management and social reproduction. To secure their families' livelihoods, these populations have been adapting their production systems and way of life to cope with uncertainties. Nowadays, they are faced with new challenges such as high demographic growth (4 percent on average), climate change, environmental concerns and global market changes, which have had major local impacts on their production system organization, dynamics and viability. We shall discuss here how livestock production sys-

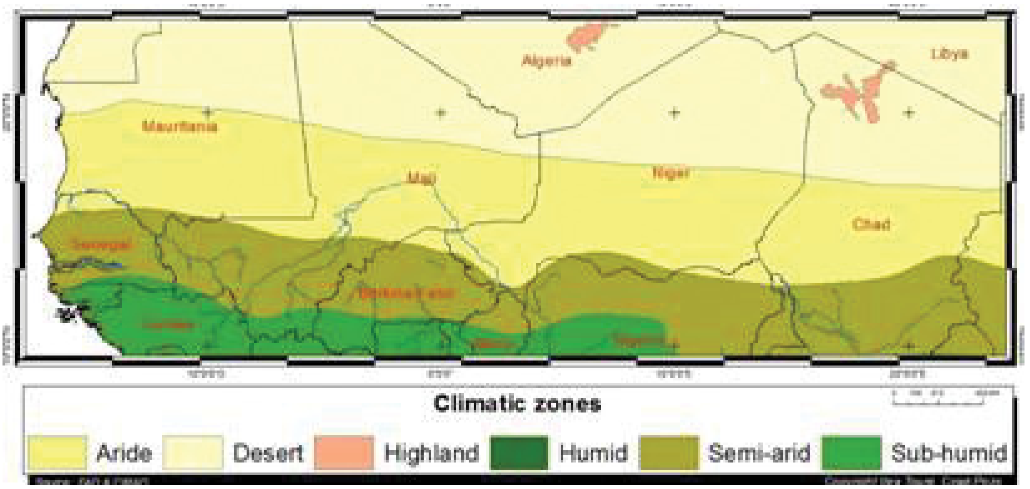

**Figure 1. Agro-ecological zones in the Western Sahel**
*Source*: FAO (Agro-ecological Zoning Database 2000).

tems in the Sahel, associated with cropping activities or not, have been shaped by this highly variable environment, and what can be said about their ability to cope with the new challenges and maintain their production systems and way of life (i.e. resilience). We will analyse how public policies could enhance their adaptive capacities to further changes and ensure population food security. Whereas the main ecological and socio-economic characteristics of production systems in the Sahelian part of Africa are broadly similar from Senegal in the West to Ethiopia in the East, we will focus our description on the countries of the Western part of the Sahel (Senegal, Mali, Burkina Faso and the Niger).

## CROP–LIVESTOCK PRODUCTION SYSTEMS IN THE SAHEL

### Characteristics and distribution

In this study, we look at crop–livestock production systems in the Sahel as defined by Sere and Steinfeld (1996), the FAO global classification of livestock systems that has been widely used and recently refined in a study on global livestock production systems (Robinson *et al.*, 2011), combining agro-ecological, production and livelihood data. Such systems, in arid and semi-arid areas, can be composed of:

– livestock only grazing systems;
– rainfed mixed crop-livestock systems;
– irrigated mixed crop-livestock systems.

These three types of systems combine crop (mainly millet, cowpea, sorghum, cotton and groundnut) and livestock activities (cattle, sheep, goats and camels) in different proportions. Figure 2 shows the distribution of such major crop–livestock production systems in West Africa. These are important systems both for agriculture and livestock production, and in terms of livelihoods in the whole West Africa, especially in four western Sahelian countries (Burkina Faso, Mali, the Niger and Senegal), where they breed the majority of the livestock population and contribute more than 30 percent to the agricultural GDP – compared with 17.2 percent in the whole of West Africa (see Table 1).

**Table 1: Importance of livestock population (x1 000) in 2004 in western Sahelian countries**

| | Cattle | Sheep | Goats | Contribution to agricultural GDP 2000 (%) |
|---|---|---|---|---|
| Burkina Faso | 5 200 | 7 000 | 8 800 | 34.7 |
| Mali | 7 500 | 8 364 | 12 036 | 48.8 |
| Niger | 2 260 | 4 500 | 6 900 | 37.4 |
| Senegal | 3 100 | 4 700 | 4 000 | 30.9 |
| TOTAL | 18 060 | 24 564 | 31 736 | 37.95 |
| TOTAL W Africa | 42 466 | 56 850 | 69 779 | 17.2 |

*Source*: Ly, Fall and Okike (2010).

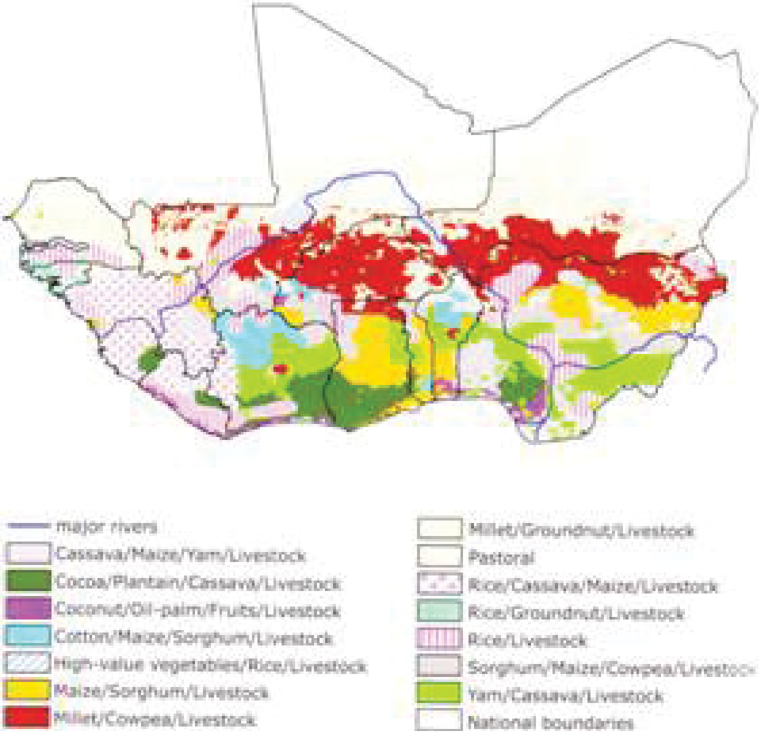

**Figure 2. Distribution of major livestock production systems in West Africa**

*Source:* Ly, Fall and Okike (2010) from Fernandez-Rivera *et al.* (2004).

In western Sahelian countries, the rural population, living in settlements of less than 5 000 inhabitants and involved in livestock farming systems, is extremely significant: at 60 percent of the total population. This share is expected to decrease down to 40 percent by 2050 (Ly, Fall and Okike, 2010).

The organization of these systems relies mainly on mobile livestock using rangelands and crop residues, from nomadic or transhumant mobile pastoral systems in the north (for the livestock only grazing systems) to more or less seasonally mobile livestock systems in the southern part (rainfed and irrigated mixed crop–livestock systems). The unconditional need for mobility of livestock (as a whole or partially), and also for families, results from rare and scarce natural forage resources, while feed is unavailable or unaffordable owing to geographical isolation, high transportation costs and low purchasing power.

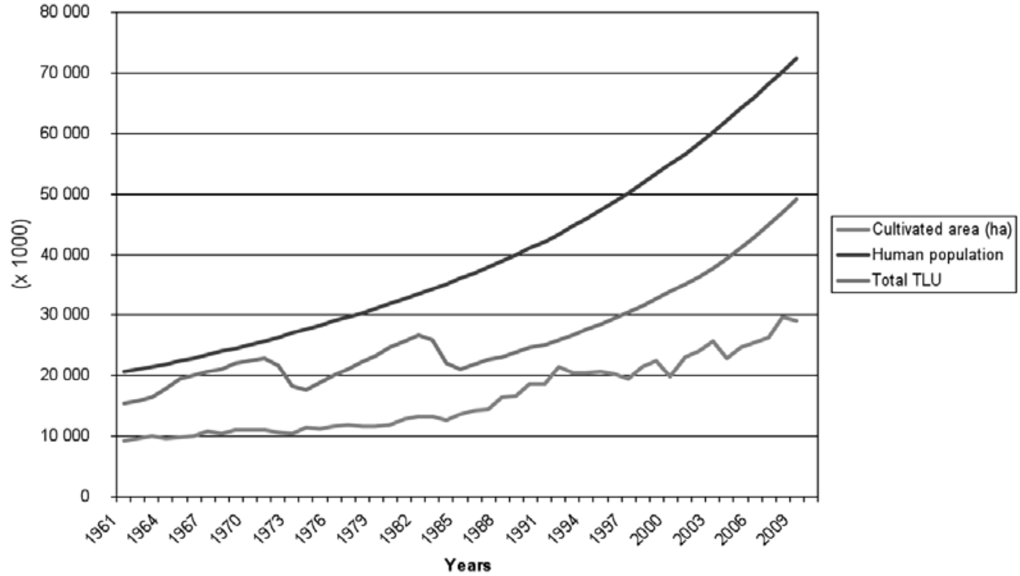

**Figure 3. Dynamics (x 1 000) of human population, cultivated area and Tropical Livestock Unit (TLU = cattle + small ruminants + camels) in four Sahelian countries (Senegal, Mali, Burkina Faso and the Niger) between 1961 and 2009**
*Source:* FAOSTAT (2012).

Actual trends (see Figure 3) show that population and livestock growth is likely to lead to more tension on land use between crop activities and pasture use.

Closely connected to an uncertain environment and variable natural resources in arid areas, the pastoralist's livelihood system in the Sahel depends on mobility, herd accumulation or ability to diversify practices and activities. The use of rangelands ranges from nomadic to sedentary lifestyles, with varied and changeable schemes of mobility (Bonfiglioli, 1990). Arid areas usually being open, in a sharing economy, the access to natural resources is based on several usage rights in order to ensure mobility and reciprocity (Thébaud, 2002). This access to land is combined with a family organization and control of production factors that varies from a patrimonial to a shared herd management (Ancey *et al.,* 2008). Women and younger men may own a part of the capital in livestock. With the opening of the pastoral areas to more diversified societies and to technical interventions of development, support to reciprocity became weaker (Sutter, 1987; Watts, 1987).

More broadly, rural agrarian societies, which integrate more or less livestock, rely on several flexible combinations of activities. In the crop and pastoral systems, farming systems oriented towards livestock (milk, cattle) and/or crop (dry cereals, groundnuts, etc.) production are more or less complementary in their land use, creating among all actors (among agro-pastoralists, as well as between agro-pastoralists and pastoralists) social relations ranging from complementarity to competition. These systems show signs of recomposition with search for off-farm incomes, and some include speculative exported crops (onions, niebe, cotton) (AFD, 2007). Moreover, they are connected to the world economy through the interventions of development, and through an increasing number of agricultural families depending on off-farm incomes and remittances (Losch, Fréguin-Gresh and White, 2011). However, these adaptations of livelihood do not guaranty their food security.

In the crop systems, the tendential deterioration of revenues from agricultural production, added to the growing pressure on land and of demography, severely limits the prospects for the build-up of capital. These factors partly explain the rural exodus, mainly agricultural, even if the number of rural people is expected to grow in sub-Saharan Africa (Losch, Fréguin-Gresh and White,2011).

### Contribution of crop–livestock systems to livelihoods and food security

At farm level, livestock provide not only part of the family food, but are also useful for crops through the use of manure and draught power. Importantly, livestock also provide an income to the economy of pastoral households, ensuring a means for saving, insurance and legacies. Livestock are therefore essential to the security and reproduction of the systems.

Locally, such systems contribute more and more to salary employment (Wane, Touré and Ancey, 2009).

At a regional level, although livestock numbers are still growing in the Sahel and contribute substantially to agricultural GDP (Table 1), their contribution to human consumption is not sufficient and does not respond to the increase of per capita meat and milk consumption because of low production levels and high demographic growth. As a consequence, trade deficit in livestock products is expected to increase (Ly, Fall and Okike, 2010).

#### *Challenges for public policies and resilience of crop-livestock systems*

In a context of open economy, under the constraints of local and global climatic uncertainty, the absence of public protection makes the adjustments pastoralists have to make in economic and social terms to smoothing and sharing shocks and constraints more difficult. This makes people more vulnerable and accentuates inequalities.

At national and regional scales, it is often difficult for public authorities to support local production, provide access to social services and ensure food security, notably in addressing price volatility. For example, the current level of import taxes in the West African Economic and Monetary Union is among the lowest in the world; prices of exported crops are not defended (Nubukpo, 2011) and sub-Saharan African countries were unable to protect regional rural populations from the volatility of commodity markets in the recent food crises.

In such an uncertain pastoral environment, marked by climate risks and price volatility, public regulations of goods and services are particularly necessary to ensure food security (Janin and de Suremain, 2005).

#### *Ecological functions*

Besides production and economic functions, the ecological functions of livestock farming gain importance on the policy agenda as environmental concerns emerge. Its contribution to soil fertility in mixed systems through organic matter transfer by livestock has been intensively studied and show higher yields in cropland than in production systems without livestock (Landais and Lhoste, 1993; Hiernaux *et al.,* 1997; Manlay *et al.,* 2004). In grazing systems, livestock also contribute to biodiversity maintenance, water cycle enhancement and carbon sequestration in rangelands where grazing pressure is moderate (FAO, 2006; Miehe *et al.,* 2010; Toutain *et al*., 2010). Greenhouse gas (GHG) emissions per output are important as forage and livestock diet quality are low but assessment of GHG emissions of such systems needs more accurate data. They also need to be balanced with other environmental and socio-economic services provided by livestock farming.

#### *Social functions*

Grazing systems traditionally fulfil various functions through diversified and accurate use of livestock capital (sales, gifts, loans, distribution, inheritance and even thefts): organization of resource management, social recognition, collective risk management, collective food security management and social reproduction.

In recent decades, more and more livestock were integrated in agricultural systems as a complementary source of income and also as a means to improve crop production by making organic matter available for soil fertility (Landais and Lhoste, 1993). At the same time, owing to climate variability (grazing systems moving southwards) and strong demographic pressure (agricultural systems moving northwards), interactions between different grazing systems became more frequent, as land, forage and organic matter management and product exchange can attest. As a result, resource management evolved through livestock lending management, common social organization for water, pastures and soil fertility management, employment for herd or crop management, marketing organization, etc., developing a new social relationship inside and between crop–livestock systems. This is even strengthened nowadays as decentralization in all Sahelian countries aims to lead to the integration of the different land users in local organizations with the aim of improved management of land and natural resources.

## RISKS FACED BY CROP–LIVESTOCK SYSTEMS IN THE SAHEL IN THE RECENT PAST

### Climate-related risks

#### *Climate variability and prospects*

Climate variability is one of the major characteristics of the Sahelian area. This variability can be observed at time and spatial scale. Figure 4 shows that the inter-annual variability of rainfall in the Sahel is not something recent. Usual average coefficient of variation (CV = standard deviation/average annual rainfall) is around 30 percent. It is also clear that, during the last century, the Sahel experienced different periods, a wet period (1950–1968) and a very dry period (1972–1995). The current period since 1996 is very dry with a few wet years. Together with this highly variable rainfall over time, the other main feature is a highly spatial variability of rainfall owing to its stormy nature during the monsoon. As a consequence, rainfall can not only be very heterogeneous on the same day at a 10-km distance but also for the annual rainfall at a 20–30-km distance. Rural populations are familiar with these characteristics (see below) and their practices are adapted to time and spatial heterogeneity of rainfall.

The main risks occur when two to three dry years cumulate with consequences on main stocks, which run short (food grain stock, rangeland seed stock, animal body condition,

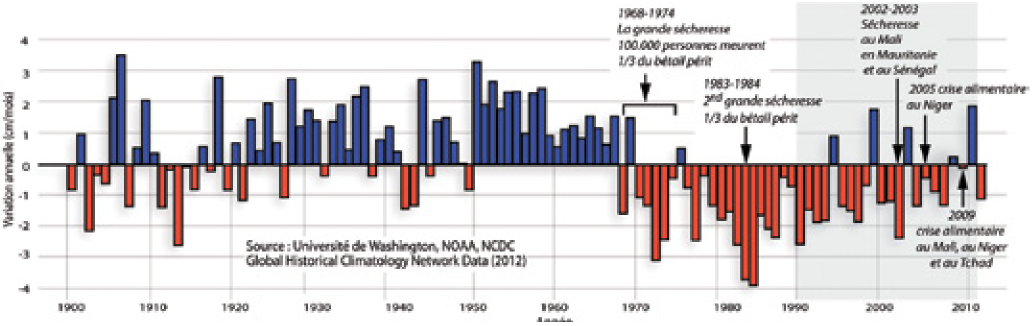

**Figure 4. Variability of annual rainfall compared with average in the Sahel between 1900 and 2010**

human health). This was observed in the early 1970s (1973–1974) and mid-1980s (1984–1985), with the severest droughts in the twentieth century with many people and livestock deaths (see Figure 4).

Actual trends for the geographic repartition of annual rainfall in the Sahel are still not so clear. Comparing isohyetals for the period 1991–2009 with average annual rainfall during 1961–1990 (Figure 5), we can identify a smooth increase of rainfall northward. This is why some authors working on the dynamics of biomass estimates in the Sahel through a vegetation index refer to a "Sahel regreening" (Bégué *et al*., 2011).

In the future, climatic prospects do not seem so clear about rainfall in the Sahel owing to the complexity of the monsoon regime, which results in very different and controversial results from recent models (Hiernaux and Soussana, 2011). Temperatures are expected to rise in a range 1.8–4 °C, but local differences are likely to overshadow global trends and a main change might result in extreme events such as heat stress, drought and flooding (Thornton *et al*., 2009).

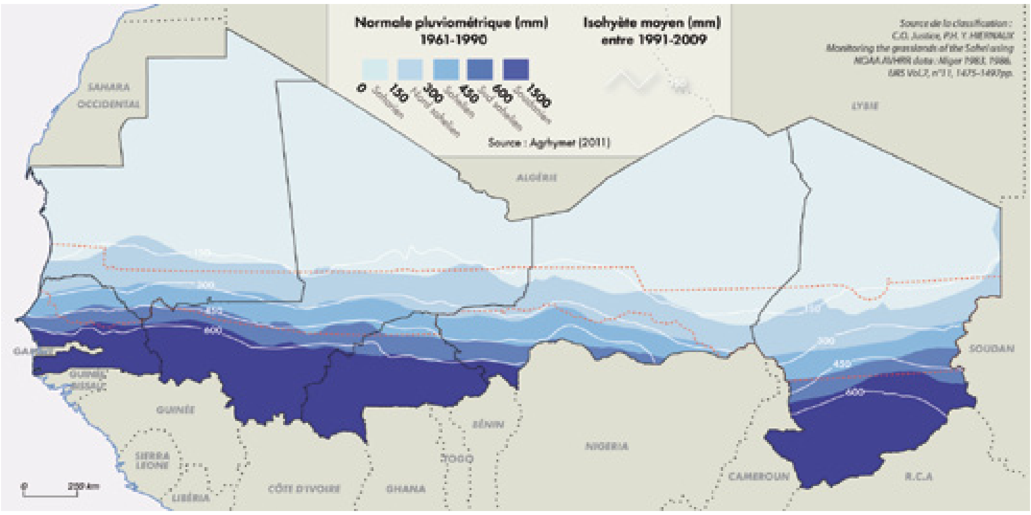

**Figure 5. Isohyetals in the Sahel during the 1991–2009 period compared with average annual rainfall during 1961–1990**

### *Effect of climate variability*

#### *Effects on distribution and production*

The positive rainfall gradient in the Sahel from north to south combined with high spatial variability can explain the distribution of the different production systems.

North to this 400-mm line, livestock systems are mainly mobile livestock systems (transhumant or nomadic, livestock only grazing systems) with lesser cropping activity up to the north. Livestock mobility, more or less linked to human mobility, is here a strategy to cope with resource uncertainty in space and time. Opportunistic management of resources has been described as a characteristic of these livestock only grazing systems and also as the best practice to produce and survive in this kind of environment (Benkhe, Scoones and Kerven, 1993).

Cropping systems in association with livestock activities (rainfed mixed crop–livestock systems) are widespread south of the 400-mm rainfall line and consist mainly of sedentary or semi-sedentary production systems. Livestock are generally kept around households where crops are grown and are fed on rangelands and crop residues. When annual rainfall is poor, livestock are frequently moved away for several weeks to find natural forage resources elsewhere, being driven by family members, relatives or sometime pastoralists (Toutain and Ickowicz, 1999). Crop productivity shows annual variations with coefficients of variation similar to those of rainfall. Variability of livestock system production is more complex to estimate. Very few studies and relevant figures are available for the Sahel at national level. We might argue that mobility allows pastoralists to alleviate this climatic variability, even if average productivity is lower than in other systems. See Table 2 for some usual performances of cattle and sheep under rainfed mixed crop–livestock systems or livestock only grazing systems.

#### *Climate change adaptation*

From climate change as predicted by the Intergovernmental Panel on Climate Change (IPCC), expected impacts of climate change on livestock systems might be more important on livestock only grazing systems as their dependence on natural rangeland is much more important. Change in quality and quantity of feed, heat stress, water availability and more frequent extreme climatic events are expected, but there is an important need to better analyse these impacts in order to understand how livestock systems would have to adapt (Thornton *et al.*, 2009).

Climate variability or change already triggered reported changes in the management of production systems over the last decades, even if it is difficult to discriminate *stricto sensu*

**Table 2: Usual performances of ruminants under rainfed mixed crop–livestock systems and livestock only grazing systems in the Sahel**

| | Annual reproduction rate (%) | Average milk production (litres/day) | Juvenile mortality rate (%) | Net offtake rate (%) * |
|---|---|---|---|---|
| Cattle | 45–60 | 1.5-3.5 | 10–20 | 14 |
| Sheep | 85–91 | - | 11–15 | 18–25 |
| Goats | 93–96 | - | 20–25 | 17–19 |

* net annual exploitation of herd production in heads

*Source:* Tyc (1994); Ezanno, Ickowicz and Lancelot (2005); Lesnoff, Corniaux and Hiernaux (2012).

climate-change adaptation measures from measures linked to the adaptation to other major drivers of change such as increase of human demographic pressure (Thébaud, 1990; Bonnet *et al.*, 2004; Ancey *et al.*, 2009; Thornton *et al.*, 2009; Ickowicz *et al.*, 2010; Bah *et al.*, 2010; Touré, 2010; Touré *et al.*, 2009):

*Crop–livestock systems*

- Increase in cropped area
- Change in sowing and harvesting dates
- Change in crop species
- Decrease in grazing cattle number but increase in sedentary draught and fattened cattle and in small ruminants
- Decrease in rangeland area vs cropped area
- More herd mobility in dry season because of less rangeland availability

*Livestock grazing systems*

- Change in livestock species contribution to herd composition. More small ruminants and less cattle owing to decrease in grass availability. In northern area, camels expanded
- Change in mobility pattern with longer distances, longer durations
- Herd routes moving southwards to more humid areas to find forage resources
- More conflicts with sedentary people in the south owing to competition for water and pasture resources
- Diversification of activities and income resources

## Economic risks

Strategies to manage risks as a result of climatic variability will have to be integrated with strategies driven by economic considerations.

Sahelian countries are dependant on the global economic environment, which was marked by an exceptional surge in food prices between 2007 and 2008; this trend continues today. Worldwide, the prices of cereals, in particular, have increased by 87 percent from the first trimester of 2007 to the first trimester of 2008 (FAO, 2008). This wide variation in food price reflects the growing uncertainty on global markets. It is often transmitted, though with great heterogeneity, to national markets (HLPE, 2011a).

The food crisis is often analysed as the result of uncontrolled variations of supply and demand at regional and local levels, owing to both structural and cyclical factors (IMF, 2006; Mitchell, 2008; RPCA, 2008a, b; FAO/OECD, 2011)[1].

These phenomena have a real impact on food and nutritional profiles of Sahelian pastoralists. However, little information is focused on animal feed because of the weak and marginal volumes at stake and yet so vital to the security of animal productive potential in Sahelian pastoral and agropastoral systems in a context of climate change (Assani *et al.*,

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[1] An exhaustive synthesis on the dynamics of price volatility and impact on food security is provided in HLPE (2011) and a synthesis on price volatility and transmission on local prices by David-Benz *et al.* (2010)

2011*)*. In fact, the global market for animal feed is also affected because nearly 36 percent of the grain produced – mostly traded on world markets – contribute up to 50 percent of the composition of animal feed in general (Harder and Jung, 2008) and contribute more and more in rainfed mixed crop–livestock systems and livestock only grazing systems. The situation has become worrisome for countries highly dependent on cereals, especially for people in structurally deficit areas of the Sahel (RPCA, 2008a, b).

In this economic risk analysis, we describe very briefly the determinants, nature and effects of the food crisis on human populations and then focus on the impacts, often weakly studied, on animal populations at a territorial and/or micro scale.

### *Crisis in world prices of food and animal feed: transmission and volatility*

The price increase has affected all agricultural commodities, but not with the same magnitude (Figure 6).

The world price of rice began to flare in November 2007 before peaking at USD1 015 per tonne in May 2008. This represents an increase of 200 percent. Wheat had a steady increase from June 2007 and reached its peak of 126 percent in March 2008, then declined without returning to its former levels. International prices of maize showed a relative decline in the third quarter of 2007 and have regularly increased until May 2008. Regarding oil prices, which have direct impact on the costs of processing and transporting food and on the price of water in Sahelian boreholes, uncontrolled increases were observed with price levels multiplied by 2.49 between 2007 and 2008 with a peak in July 2008 up to USD1 225 per tonne of diesel.

Given the contagion effects that are due to the strong market integration, an acceleration of propagation of shocks is often expected, with transmission of the world price variations to domestic prices. However, this effect had a more or less direct impact according to the configuration of national markets and the extraversion of consumption patterns (Meuriot *et al.*, 2011).

Indeed, for animal feed markets, for which more than half the inputs come from imported grain (Harder and Jung, 2008), the increase in world prices has been strongly felt (Assani *et al.,* 2011).

However, price volatility in African countries is likely more endogenous. It is influenced by the ambivalent function of market segmentation, the configuration of which can either increase price volatility, preventing any possibility of compensation, or mitigate the effects of volatility (Meuriot *et al.*, 2011; HLPE, 2011a).

Moreover, it has to be noted that the effects of rising prices have been slightly smoothed for the Sahelian countries by favourable exchange rates between a weaker US dollar (the main currency in international trade) and the Franc Cfa, which has a fixed exchange rate with the Euro (Assani *et al.*, 2011).

### *Causes of rising animal food prices: case study of Senegal*

The origin of the crisis of food and energy is multidimensional and largely documented in particular by FAO (2008), HLPE (2011a, b) reports and the report for the G20 (FAO/OECD 2011).

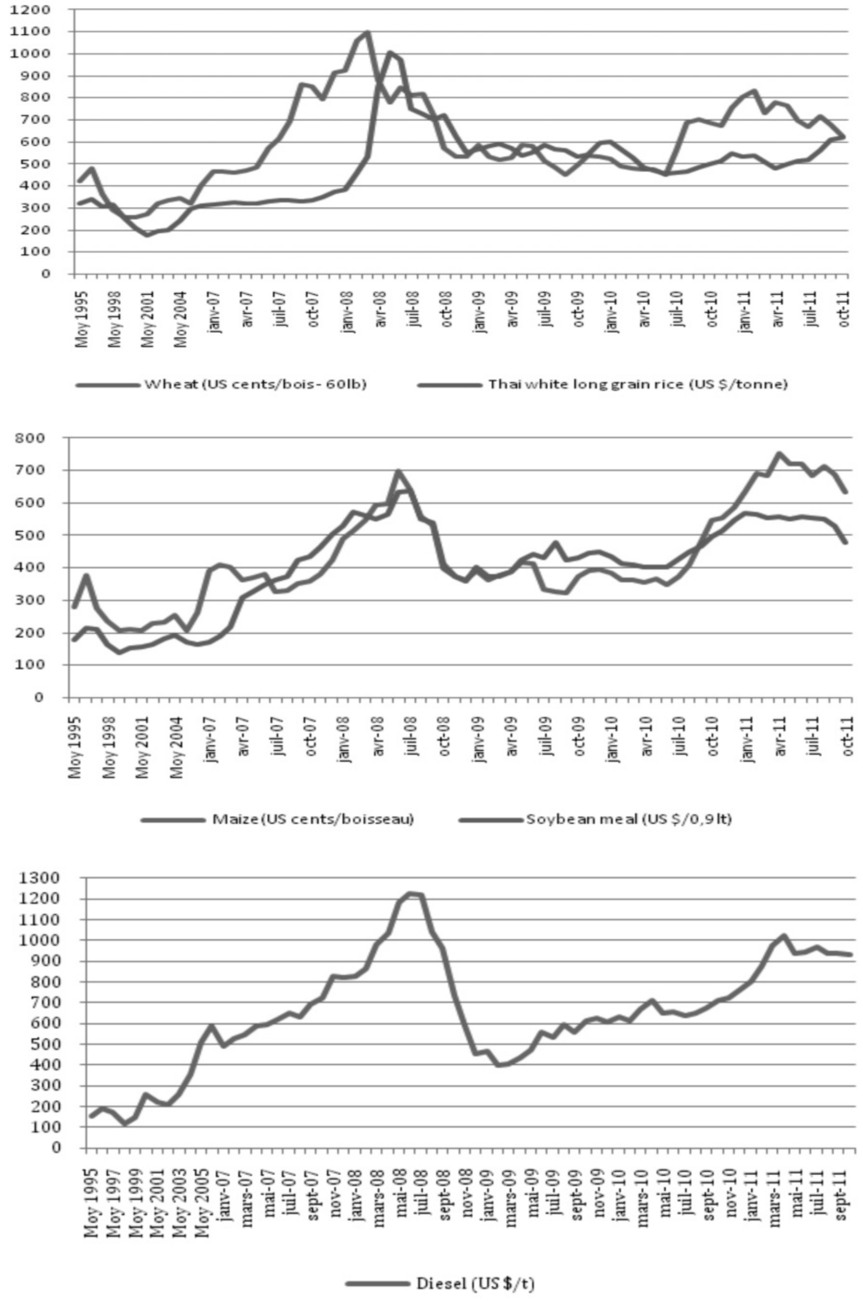

**Figure 6. World price trends of cereals and oil**

For animal feed, the imbrications of international markets and national markets dominated by imports of inputs have strongly influenced the prices observed in Sahelian countries.

However, these price changes do not come only from variations of international prices; phenomena of margins also played a role. For illustration, in Senegal, there were significant

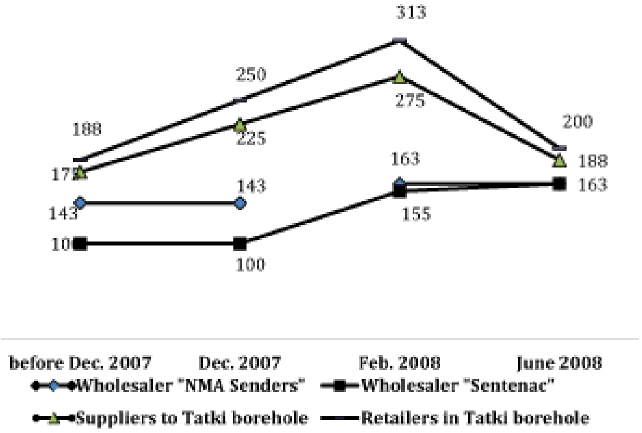

**Figure 7. Evolution of the price of ruminant feed by type of seller (xof/kg)**

differences in prices between various feed providers to pastoralists, the final purchaser. Until December 2007, the latter purchased animal feed at prices from 1.9 to 2.5 times higher than those paid at the cheapest factory (Figure 7).

### *Effects of price increase on crop and livestock markets in the Sahelian areas*

One of the main consequences of the variability of grain prices lies in food security and nutrition vulnerability of pastoral populations.

Sahelian pastoral households often turn onto markets to sell animals and buy commodities like cereals (Wane, 2010; Wane, Touré and Ancey, 2010a, b). «Normal» or «unusual» movements of food and feed prices affect decisions on management and marketing of livestock in the Sahel. During the feed and food crises in 2007 and 2008 in Senegal, pastoralists came on livestock markets with unusual animal offers influencing market parameters through prices and quantities. For example, exceptional sales of small ruminants in February 2007 were realized during the period of feed crisis, which forced farmers to sell more to cover their expenses. The structure of sales of adult cattle has also changed. There were more beef proposed on the markets as well as cows with calves; thus showing the weakening of the pastoral micro-economic model (Wane, Touré and Ancey, 2010a). Such effects are similar to the ones in responses to drought, described in Gitz and Meybeck (2012).

Regarding markets, pastoral populations are also involved in trade exchanges without necessity and, sometimes, for opportunistic reasons. This behaviour assigns a central role to the "terms of trade" in agricultural markets. The terms of trade alternate periods of low and high variability, which is due mainly to the sharp fluctuations in grain prices highly correlated with harvest levels, which in turn are largely dependent on erratic rainfall in the Sahel.

The terms of trade have changed significantly for various reasons in Africa in relation to geographical and historical contexts (Dietvorst and Kerven, 1992). In the Sahel, especially in the Niger, because of the Fulani domination in the possession, management and marketing of animals and also owing to their specific dietary requirements, the terms of trade were soon dependant on the relative values between livestock and cereals (Dietvorst and Kerven, 1992): mainly between cattle and cereals (Dupire, 1962; Baier, 1980; Bonfiglioli, 1988) and, more recently, also between goats and millet in Mali, for example (Wane, 2010; Wane, Touré and Ancey, 2010b).

Until the aftermath of independence, terms of trade were characterized by very high variability mainly due to significant price volatility strongly correlated to millet crop quality and therefore rainfall (Sutter, 1982). Today, phenomena combining climatic and economic aspects (speculative transmission of price increases, price volatility, effects of substitution of imports by local products) exacerbate the instability of terms of trade (David-Benz *et al.*, 2010).

In 2010, the Sahel once again experienced a deep crisis highlighting the vulnerability of pastoralists for food and nutrition (Figure 8). In Mali, for example, a comparison of inter-annual terms of trade goat-millet in 2010 largely inspired by biophysical approaches

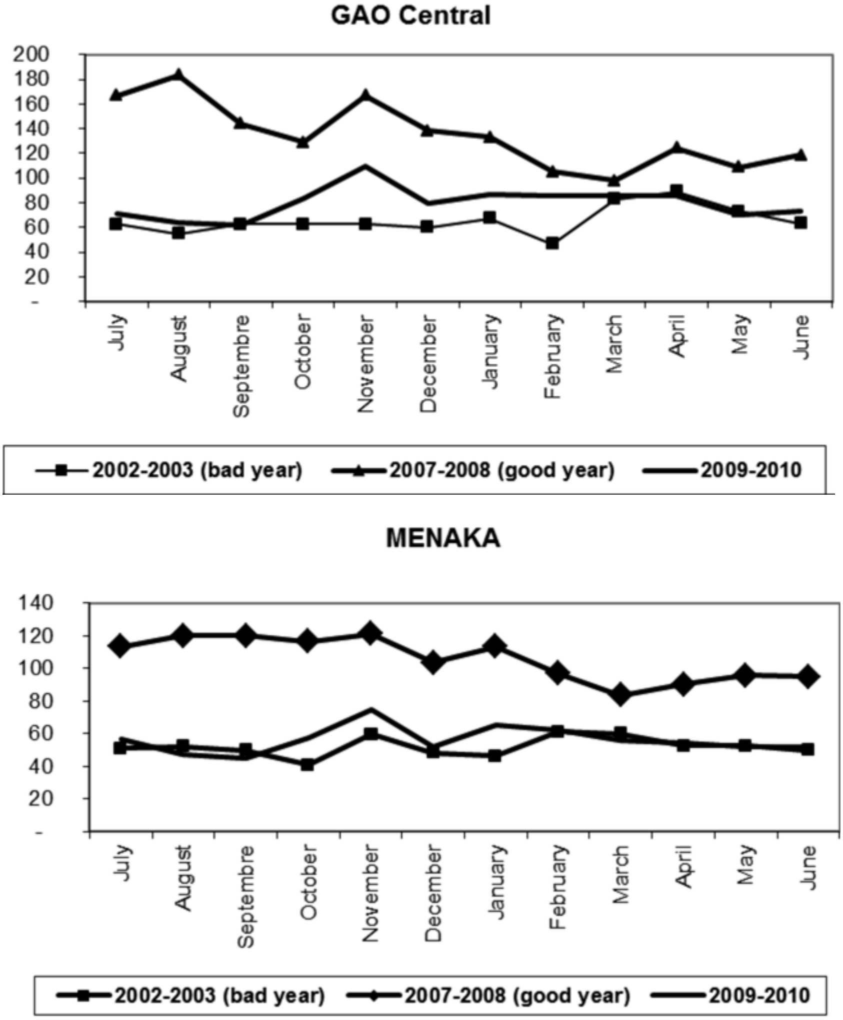

**Figure 8. Inter-annual comparison of terms of trade kg millet/ goat**

proposed in the Sahelian context (Touré *et al.*, 2009), compares the terms of trade in 2010 related to good or worse years of the last decade, declared by the household investigated according to their perceptions. This allows us to obtain a relatively quick review of the crisis. With reference to markets in Gao central and in Menaka, the terms of trade goat-millet of the year 2010 are largely below those of a good year.

These two markets have terms of trade flirting with those observed during the worst years of the last decade. Although a slight improvement is noticeable after the harvest period in October, ongoing deterioration is such that by February 2010 (Menaka) and March 2010 (Gao central), the curve of the terms of trade merged with the curve of bad years (Wane, 2010; Wane, Touré and Ancey, 2010b).

As a conclusion, we could say that overlapping of markets at different scales (international, national, local) leads to transmission of higher prices and volatility but that the configuration of national markets, styles of consumption and especially public policy regulation have a mitigation effect (policy measures to contain inflation and to support the purchasing power: subsidies, price and stocks controls, simplification of market procedures, boost of local production and reconstitution of food réserves).

For Sahelian countries, it is needed and urgent to harmonize methods on market data collection and processing, to develop appropriate concepts and indicators in order to prevent food and nutritional crises and to develop a multidimensional approach to food security, taking into account the availability, access and use of food and the stability of production and prices. This dynamic must be articulated with the ongoing discussions within the Technical Committee of the Harmonized Framework jointly managed by the Comité Inter-états de Lutte contre la Sécheresse au Sahel (CILSS) and its partners (US Agency for International Development, World Food Programme, FEWS.NET, FAO, MIFRAC, IBIMET-CNR, CIDA, Care and the European Union).

## Land tenure risks

### *Land-use change, changes in the spatial distribution of production systems and underlying drivers*

Sahelian Africa has one of the fastest growing populations in the world. Population gains have been accelerating since 2000 (Figure 9). This demographic jump can be explained by a continuing high fertility rate combined with a fairly rapid drop in mortality rates. The total population for the Sahel region[2] is expected to double by the year 2030, to almost 100 million people, a scenario in the order of +2.5 percent per year. Urbanization will continue at a considerable pace, expected to reach +5 percent in the capitals. However, the rural population, which still represents 70 percent of the total population (as of 2010), will continue to increase and should remain the majority up until 2035.

The densification of rural areas is a central driver to the dynamics of land occupancy in the Sahel. Such a densification is occurring in originally thinly inhabited areas. which are subject to major spatio-temporal rainfall hazard, low productive and ecologically fragile.

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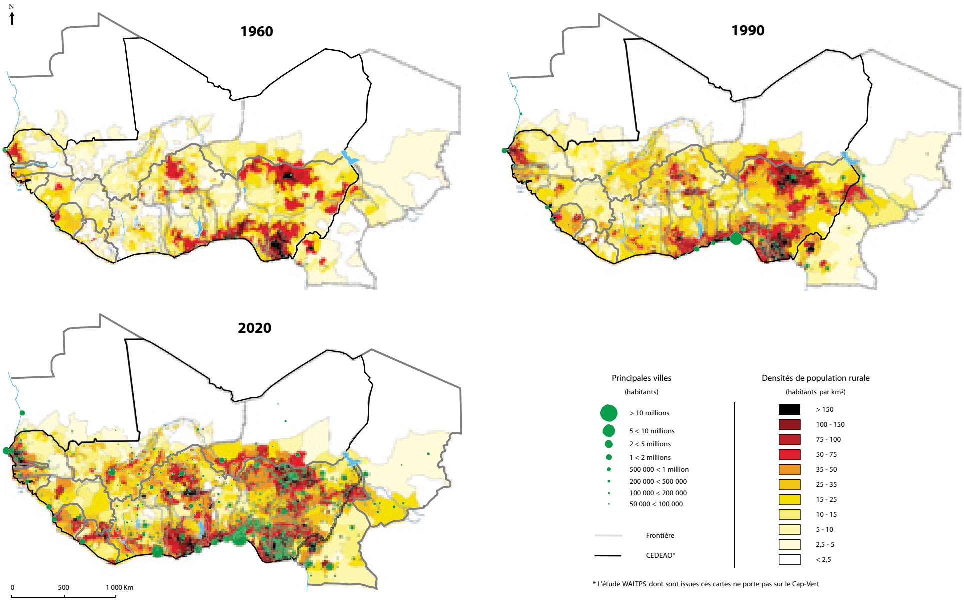
[2] On the basis of CILLS member countries (Burkina Faso, Cape Verde, the Gambia, Guinea Bissau, Mali, Mauritania, the Niger, Senegal, Chad).



Source : Etude des perspectives à long terme en Afrique de l'Ouest (document de synthèse, 1998)

**Figure 9. Population of West Africa between 1960 and 1990, forecast to 2020**
*Source:* ECOWAS (2005)

Producers have adapted to these constraints by developing production systems based on extensive and mobile crops and animal production, all of which take up considerable space. Today, as it requires less financial resources, cultivation is developing more rapidly than livestock herding, an obvious advantage where purchasing power is low.

Consequently, cropping is making the greater strides and the effects of this are being felt in rangelands to the North in the form of both rainfed and irrigated agriculture. It is also gaining space in the forest areas to the South through a reduction in summer fallow and through wood harvesting. At the same time, livestock herds have recovered from the severe droughts of the 1970s and 1980s and are now on the increase.

Taking advantage of a fall in the incidence of trypanosomosis, livestock holders have settled down with their herds in the vicinity of the Sudanian zones, which offer easier access to the markets as well as proximity to the transhumance staging points.

In South Sahelian zones, the pastoral area is shrinking or being blocked by the double pressure of cultivation and urbanization. In these areas, the activities of livestock rearing and that of cultivation were once relatively independent. Now they are vying for access to the same territories or the same resources (water, land, forage, timber). These activities remain poorly integrated and are still based on low-intensive production systems that are technically not very productive, in addition to being space consuming. The mobility of the herds of Sahelian pastoralists is clearly hindered in today's environment.

The closing off of access points to rivers has become a serious difficulty in the wake of large-scale hydro-agriculture projects, such as can be found in the Senegal River Valley and in the Inner Niger Delta. The demographic pressure in the southern agricultural regions, which has reduced fallow land and natural pastures, has led to the paradoxical situation today where the rainy season is a season when access to pasture is a thorny issue.

Land tenure and land use are thus major issues across the entire Sahel. Competition is fierce, sometimes resulting in violent conflict. Within this context of intense land pressure, traditional rules of access to resources are becoming less and less effective. Modern regulations, which in most Sahelian countries recently recognized collective land-use rights for pastoralists, are rarely implemented in the absence of land titles and enforcement procedures. Confusion abounds and the law of the strongest prevails, exposing modest producers without land-use rights to the risk of large-scale land appropriation.

### *Large-scale land acquisitions*

For several years now the African continent, and also the Sahel, has been affected by the phenomenon of large-scale land acquisition (HLPE, 2011b). Eager to raise capital and modernize their agriculture, many states have turned to private foreign investors. The consequences of these large projects for the host countries and their populations are not negligible. In fact, such projects are radically transforming regions. The investors often "sell" their project as an injection of development capital when in fact they are grabbing hold of resources principally used by the local populations but not formally owned by them (land, water). The contentious decision to favour agro-industry over family farming, the latter being viewed as unproductive and insufficiently market-oriented, runs the risk of foreign companies acquiring lands on a formal, enduring basis to the detriment of local populations. Moreover, produce on those lands is often destined for export: cane sugar, cotton, vegetable oils (groundnut, sunflower), biofuel (Jatropha, sugar cane) and vegetable crops, shipped directly to the investor countries (e.g. rice). And once the competitor gets hold of the land, it then controls the water as well, as is especially the case in irrigated areas. Private investors will only commit if their water supply is assured. The signing of formal contracts with the state guarantees them privileged access.

### *Land management policies and governance*

As land becomes less and less available, competition for access to its resources becomes increasingly tougher, leading to more attempts at land appropriation. Land legislation is directly based on western origins. It is more suited to the needs of sedentary activities such as cultivation rather than to mobile activities like pastoralism, which is difficult to define in relation to individually appropriated space. Most of the legislation currently in force in the Sahel is very ambiguous about the status of pastoral lands. Recognition of traditional rights to pasture is already well established, yet remains the exception rather than the rule in an agricultural setting. Pastoralism is not generally seen as an effective means for improving farmland in the same way that cultivation is. As a result, rights on pastoral lands generally remain precarious and not recognized by institutions (HLPE, 2011b), especially in the strategic areas of lowlands, riverbanks, wet valleys, forestry and pastoral reserves. Sustainable use of rangelands for organized pastoral groups has been attempted on several occasions, notably through "pastoral units". These, however, were one-off measures with very mixed results.

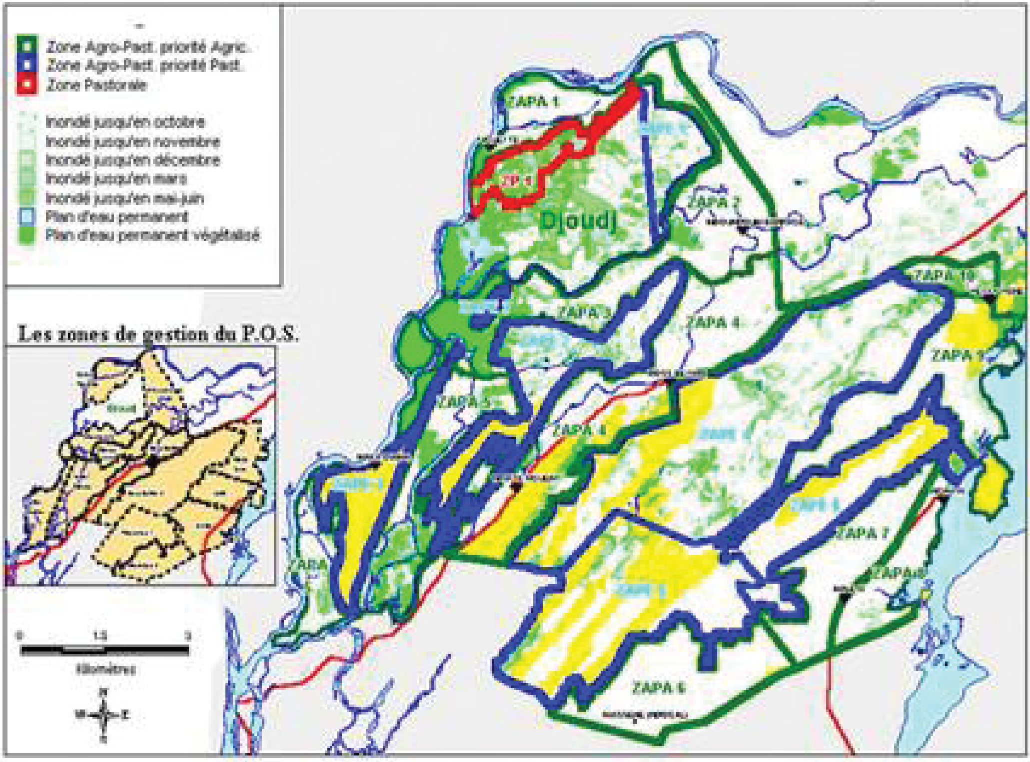


**Figure 10. Delimitation of pastoral and agro-pastoral land use in the rural community of Ross-Béthio in northern Senegal**
*Source:* Diop et *al.* (2001)

Today, institutional environment is moving rapidly. In the context of the democratization movements dating from the 1990s, the Sahelian countries have initiated decentralization policies to build and strengthen forms of local governance expected to be more democratic and participative. The creation or strengthening of local governments endowed with elected councils, legal personality and proper resources has radically changed the institutional landscape and governance at the central and local levels. Admittedly, modern land-use and land-tenure regulations can appear confusing in their local application, especially where collective land management is necessary. The law of the state sometimes bumps up against traditional rules (rights of new arrivals, user rights) and local practices for resolving conflict. But these new stakeholders, communes, local governments and inter-regional authorities are gaining more and more power for managing their lands and resources. They are mandated to set up modes of governance in accordance with the current laws and regulations, while at the same time taking into account local conventions and customs. They are in charge of organizing their territory between activities (livestock, cultivation, fishing, forestry, national parks, habitats); they can intervene with the support of competent advisers in procedures of land allocation (land titles, leasing); and they can be called upon to resolve conflicts. Senegal was a pioneer in this respect and is today relatively advanced, particularly among the rural communities of the Senegal River Valley where land-use planning has been integrated in local governance processes (Figure 10).

These policies, nevertheless, remain difficult to fully implement on a large scale. Depending on the country, decentralization is more or less complete. And, despite all the promises of decentralization, it has not fully restored control over land management and natural resources to the relevant actors. Livestock farmers are still often left behind these land management processes as they are not enough self-organized. The risk for them to loose control and access to strategic resources (pastures, water) is still high. Bearing in mind the allocation of considerable chunks of land to agro-business (see above), the risk of the state taking back control is a very real one. Furthermore, the juridical model must be concurrently legitimized by the people and sanctioned by the state.

### Sanitary risks

Sanitary risks for livestock in the Sahel mostly belong to history, thanks to epizootic control. Many efforts have been made in the past decades in vaccination (rinderpest, pleuropneumoniae, anthrax, small ruminant pest, etc.) and tick-borne disease control with veterinary services and research. For livestock herders, risks are usually managed through control of livestock entry into the herd, water point control and the use of local medicine or even vaccines (pleuropneumoniae). Nowadays, rinderpest is officially eradicated in the world and most other epizootics are quite under control. Nevertheless, production losses owing to health contraints of livestock in the Sahel remain high, especially for young animals (infectious diseases, parasites, nutritional deficits) where environmental, feed and sanitary factors combine to result in high mortality rates (around 20 percent usually; Tyc, 1994; Ezanno, Ickowicz and Lancelot, 2005). These risks for young livestock might be one of the major foci to improve productivity and risk management through participatory approaches between herders and scientists. Other sanitary risks related to climate change in the Sahel are today very complex to estimate (Thornton *et al.,* 2009).

## VULNERABILITY AND ADAPTATION STRATEGIES OF CROP-LIVESTOCK SYSTEMS

### A proposition for a model of vulnerability applied to crop-livestock systems

Considering the main risks faced by crop–livestock production systems in the Sahel described in the previous sections, we propose here an adapted model of vulnerability for these systems (Figure 11). It has been built considering important literature on inequality and vulnerability applied here to poor populations in rural environments (Sen, 1981; Swift, 1989). The major modification to the model consisted of taking into account the tight integration of social and biophysical factors that play major roles for vulnerability of crop–livestock systems. This vulnerability is then not only an exposure to different types of risks that affect endowments but also a function of capabilities to react or anticipate, through entitlements owing mainly to social, demographic, and economic attributes and positions. Dealing with those risks is also fully integrated in the normal life of these people considering their highly variable environment (Chambers, 1990; Van Dijk, 1997; Bovin, 2000).

### Adaptation strategies

The food security of the sub-Saharan rural population relies on its capacity for making productive investments, stocks and recourses (Swift, 1989). In the case of pastoralism and

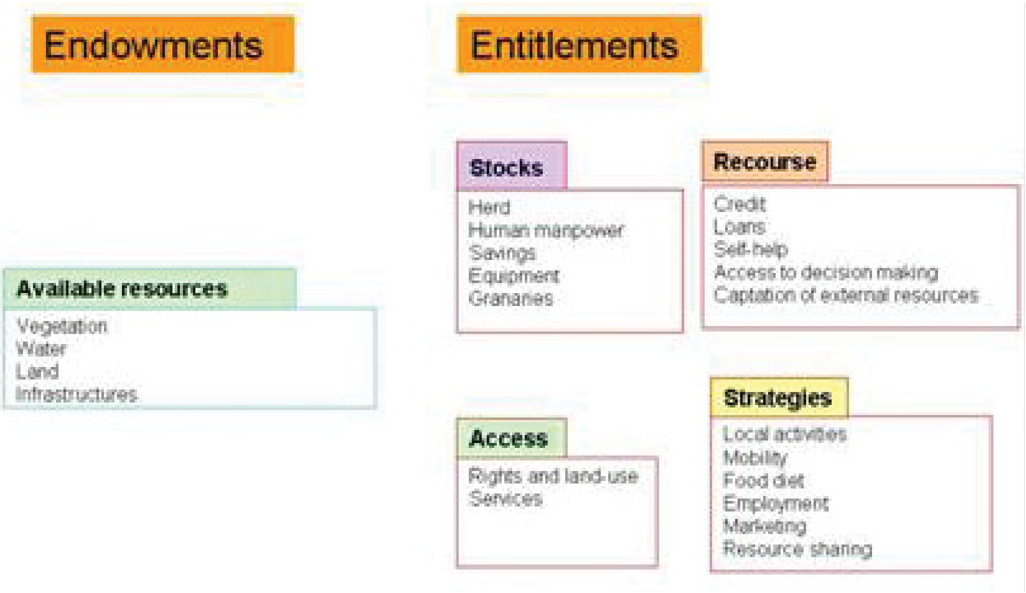


**Figure 11. Model of vulnerability proposed for crop–livestock systems**
*Source:* Ancey *et al.* (2009)

agro-pastoralism in arid areas, where natural resources are uncertain and scattered, herd mobility is central to these strategies. Furthermore, many studies (Khazanov, 1984; Kerven, 1992) have demonstrated the technical need of pastoralists to exchange with the outside world and have flexibility in their use of markets.

There is little comparative analysis concerning the rural exodus of pastoralists and farmers. From one generation to another, pastoralists should benefit from the numerical growth of herds, contrarily to farmers that from generation to generation are exposed to the family land division. In addition, livestock have a constant need for labour, as opposed to agriculture, which shows seasonal peaks of work. Aside from this, mobility allows pastoralists to avoid the local droughts. Finally, extensive livestock familial economy might not be as exposed to external shocks (volatility of world prices, etc.) as the export-oriented agricultural sector has been (HLPE, 2011a). These structures and strategies contribute to the hypothesis that pastoral resilience is greater than agricultural resilience.

The agreements regulating the access to resources (land, water, pasture), the productive strategies managing labour and livestock, the use of local mutual assistance networks of funding and transfers, evolve and form different resilience profiles in these production systems (Manoli *et al.*, 2010).

This latter work carried out in Ferlo (Senegal), in 2009[3], helped to identify four main resilience strategies depending on the context and wealth of producers:

- The large producers of cattle and small ruminants manage their income, their relationship networks, their frequent moves, and their information. They often innovate their

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[3] ANR research project “Contribution of livestock to the reduction of rural population vulnerability and to the promotion of their adaptability to climate and society changes in Sub-Saharan Africa” (ANR-ECLIS), 2009–2012.

farming practices and their other activities: cattle trade, diversification creating value-added, wage earning. Their resources are not exclusively local.

- A second group of wealthy livestock producers invest mainly on the income from herds and devote their work to herd maintenance and herd enlargement.
- The poorer livestock producers secure their way of life by diversification in small activities, which forms the basis of their survival. Trade activities by women outside the camp are essential.
- Finally, other poor livestock producers rely mainly on social networks and social support; particularly the mutual sharing of human resources and herds to allow their transhumance.

A survey conducted in the north of the Niger, in 2006, about the food crisis in pastoral regions, reveals that migration networks contribute to resilience, identifying three main ones (Ancey, 2006):

- Between the north of the Niger, the south of Algeria (Tamanrasset) and of Libya, migration networks and smuggling circuits allow migrants to find a job quickly and to send money to their families in the Niger. These same networks supply the shops and markets in northern Niger with Algerian and Libyan food (pasta or "maca", sugar, etc.) and basic products.
- In some villages in the Niger, in more southern agricultural areas, the exodus, which is an integral part of the functioning of pastoral and agro-pastoral systems, goes towards villages in the south neighbouring countries, up to the markets of the coastal cities (Lome, Malinville, Abidjan, Lagos, etc.). Relocation represents a strategic part of the family's income. But new destinations appear, especially towards Cameroon and Gabon, and in a crisis situation precipitated departures increase, without any certainty of integrating a successful network. In these cases, relocations are almost non-existent.
- Finally, other flows drain people to the capital, Niamey, mainly those without access to means of production, who have lost their herd or conceded their land. Isolated individuals try to help their rural families, but this migration to survive does not create money transfers while also sustaining an entire family in town.

These examples of migration from remote pastoral areas inside the subregion show the geographical diversity and the unequal capacity of migration networks to transfer funds from marginal and occasional assistance up to structural transfers, crucial to rural households' survival. But in a crisis situation, challenges appear, as migrants do not integrate efficient established networks (informal social protection); on the contrary, they face more and more risks, and travel further distances with a growing uncertainty.

In all cases, these systems are generally associated with low levels of human development: infrastructure and public services are defective, especially in pastoral areas; the resilience of families relies firstly and mainly on two pillars, for which they are on their own: mobility and diversification of activities. In Ferlo (northeast of Senegal), in 2009 and 2010, as well as in the Niger, in 2005, these resilience strategies ensured the survival of livestock and households.

Nevertheless, we should pay attention to networks and strategies of human mobility; herd mobility has been well documented (rationale, conditions, distance, etc.) and may hide that herders were sometimes forced migrants (Boutrais, 1999; Kerven, 1992) and that nowadays other migrations are to some extent a way to increase resilience of vulnerable systems. These networks and roads of migration towards saharian countries (Algeria, Libya), southern agricultural areas in Sahelian countries (Mali, Burkina, the Niger) or foreign regional countries (Cameroon, Central African Rep., Nigeria, Togo, Benin) are now facing changes and new constraints (such as civil wars, insecurity) in the whole region, raising new challenge for migrants in the search for work and remittances.

## Proposed indicators for vulnerability assessment of crop–livestock systems in the Sahel

From the model of vulnerability proposed for crop–livestock systems and the knowledge on adaptation strategies presented above, it is possible to identify indicators that would allow anticipation of the capabilities of crop–livestock systems to cope with the major risks faced in the Sahel.

Considering the four main types of risks described in this paper, ongoing research work on livestock systems' vulnerability in West Africa (Hiernaux *et al.,* 2010) suggests analysing the capabilities and potential response to crisis at different levels of organization: the national or agro-ecological zone level, the rural community level, the village or pastoral unit level and finally the family or farm level. We shall give here a few examples of these indicators to illustrate for each of the four types of risks what might be used as indicators for vulnerability assessment.

Indicators proposed in these tables are not exhaustive and still need more in-depth analysis and validation but they illustrate some important issues:

- Response to crisis and risk management for vulnerable populations are multiscale and multistakeholder matters. It needs a participatory and collaborative approach at different levels of organization including farmers, local stakeholders, politics, private sector, etc.
- Some indicators of vulnerability are shared between different types of risk (mobility, diversification of revenues, access to resources, etc.) but others are relevant to a specific risk (i.e. water availability for climatic risks; soil fertility for land tenure risks).

***Indicators of vulnerability to climate-related risks for crop–livestock systems***

| **Level of analysis** | **National or agro-ecological zone** | **Rural community** | **Village or pastoral unit** | **Family or farm** |
|---|---|---|---|---|
| Indicators of vulnerability to climatic risks | Water availability in time and space<br>Vegetation and animal biodiversity<br>Natural biomass availability<br>Relative cropping areas related to population<br>Pest distribution | Water infrastructure<br>(Not specific) | Access to water<br>Payment for water<br>Forage stocks<br>Mobility ratio<br>Food stocks | Type of mobility<br>Livestock and food sales<br>Herd size and cultivated area/size family<br>Livestock feeding practices<br>Available labour<br>Diversity of income |

### *Indicators of vulnerability to economic risks for crop–livestock systems*

| Level of analysis | National or agro-ecological zone | Rural community | Village or pastoral unit | Family or farm |
|---|---|---|---|---|
| Indicators of vulnerability to economic risks | (Not specific)<br>Available financial services: insurance, credit, grants<br>Revenue structure | (Not specific) | Sales structure modification<br>Terms of trade<br>Low food diversity<br>Market distance<br>Market dynamics and access<br>Access to information on markets<br>Unusual mobility | Diversity of products<br>High-value products<br>Decreased number of daily meals<br>Use of high-quality inputs<br>Integration in value chain<br>Self-consumption level<br>Diversity of income |

### *Indicators of vulnerability to land tenure risks for crop–livestock systems*

| Level of analysis | National or agro-ecological zone | Rural community | Village or pastoral unit | Family or farm |
|---|---|---|---|---|
| Indicators of vulnerability to land tenure risks | Relative area for livestock, forest and crop farming<br>Water point density<br>Irregular mobility<br>Soil fertility decrease<br>Water and carbon cycles<br>Regulation and legislation texts | Demographic pressure<br>Collective management of regulations<br>Local associations' dynamics<br>Frequence of conflicts<br>Integration of all stakeholders in decision processes<br>Land appropriation<br>Land-use planning | Management plan<br>Water and other resources and input pricing related to type of users<br>Stakeholders representation<br>Pressure on natural resources and soil degradation<br>Low livestock and crop productivity<br>Watering time<br>Unusual mobility | Date of settlement<br>Mobility type<br>Demographic structure of family<br>Access to resources<br>Distance of farm to resources and services<br>Local status<br>Land tenure and rights |

### *Indicators of vulnerability to sanitary risks*

| Level of analysis | National or agro-ecological zone | Rural community | Village or pastoral unit | Family or farm |
|---|---|---|---|---|
| Indicators of vulnerability to sanitary risks | Disease prevalence for humans, livestock and crops<br>Quantity of discarded products<br>Decrease in quality of products<br>Veterinary services | (Not specific) | Disease prevalence for humans, livestock and crops<br>Level of productivity and losses<br>Sales ratio<br>Access to sanitary services | Use of non-official sanitary products<br>Food and feed shortage<br>Herd structure<br>Use of sanitary services |

- The identification of indicators needs to be based on knowledge about farmers' strategies to cope with risks but also on a whole participatory process among scientists, farmers and policy decision-makers. This process is necessary to get relevant indicators and to build a comprehensive analysis of rural vulnerability and the way agricultural systems cope with risks and adapt their production system to changes.

## OPTIONS TO ENHANCE ADAPTATION STRATEGIES OF CROP–LIVESTOCK SYSTEMS

### Integrated policies to develop crop–livestock systems able to cope with various risks

As developed in previous parts of this document, enhancing resilience of crop–livestock systems means to increase the capacities of farmers to adapt to different types of shocks (climatic, but also economic, sanitary and related to land and demographic pressure) that have been part of their life for decades. Analysis of their strategies to cope with these events shows a number of strategies and securization systems (mobility, diversification of activities and incomes, food security, intensification, collective management, share of resource etc.) that involve not only their own capacities, ideas and skills but also the resources (biophysical, human, institutional, economic, etc.) present in their environment at different spatial scales (village, rural community, regional or national). As a consequence, a global, integrated and multiscale approach is necessary to build appropriate policies to enhance resilience and food security in crop–livestock systems.

The policy context is recognized as a major factor for enhancing the adaptation capacity of farmers to their changing environment (Steinfeld *et al.*, 2010). This underlines the need to better understand the institutional environment of crop–livestock systems, and to better assess the priorities for regional, national and local policy options.

In the following sections, we highlight three main dimensions and building blocks of integrated strategies for the resilience of crop–livestock systems, where capitalization, food security, livelihoods and market production could be objectives jointly pursued, with specific priorities according to national and local contexts.

#### *Land tenure dimension*

The land tenure policy debate in arid and subarid areas leads to at least two sets of representations.

The first set of representations is one of conflicts of property rights, according to private interests (individual or collective on several bases: household, village, ethnic group, etc.), which may be complementary, concurrent or opposite. Recent developments in the field of rangeland management suggest the need for more flexible strategies for natural resource use (Behnke, Scoones and Kerven, 1993); the analysis of risk suggests that multiple property regimes provide optimal settings for farmers and pastoralists (Van den Brink, Bromley and Chavas, 1995). From this point of view, the main challenge for land tenure policy in arid areas is to implement rights and processes in order to secure pastoral mobility in a peaceful context. Many assessments and some strategic and operational options have been provided by scientists and experts whose key words were: rules, laws, decentralization, self-management empowerment, external and local investments, cattle and village water supply, transhumance trails (Swift, 1989; and others). Land tenure policy is part of this chain, according to the hypothesis that accurate and well implemented rights and technical investments will provide security and welfare for people, entitling them to manage rangeland and preserve ecosystems.

Another set of representations of the land tenure policy options looks at the development of arid areas, not as a compromise of rights, or a chain of negotiations, investments and entitlements, but as a common good – and points out a geopolitical stake in Saharian margins (Sahel). The preservation and "valuation" of pastoral resources, and the promotion of household welfare (meaning a better standard of living, according to their choice of livelihood, which opens another huge field of questions), are part of the rural regions' development process in sub-Saharan Africa. For these many regions caught in a poverty trap, "solutions will have to come from contextualized policy interventions at the country level, as well as from initiatives capable of bringing about stronger regional integration (…). To insure that rural demand is met with an adequate supply of goods and services, governments must support local investments through adequate provision of public goods" (Losch, Fréguin-Gresh and White, 2011).

This represents land tenure as part of local integrated development policy. It underlines that, in case of dilemma, the economic transition should prevail over livelihood preservation.

The challenge for land tenure policy, in arid areas inhabited by pastoral populations both adapted to their environment but in need for better standard of living, facing structural constraints and changes, is then to consider, conciliate or make a choice between these two options.

### *Governance dimension*

A public policy might be viewed as a programme of action mainly driven by the state or by its government. In that conception, a public policy is a system of regulatory measures, laws and funding priorities concerning a given topic promulgated by a governmental entity or its representatives. This vertical approach, however, does not allow an understanding of the importance of multilevel and pluri-actors' decision processes that characterize the institutional environment of crop–livestock farming (Losch, 2008). For that reason, we will rather consider the public policy as "*normative structures that shape the actions of individual and collective actors, as well as organization*" (Lascoumes and Le Galès, 2007). In that conception, policy options will refer to multilevel governance, i.e. to individuals in interaction, exchanges, coordination mechanisms, group building, norms and conflicts.

#### *The regional integration process*

Regional economic and political integration has strongly affected the macro-economic context, infrastructure and overall agricultural policies in the Sahel. The constitution of the West African Economic and Monetary Union (WAEMU) single market and, more recently, of the Economic Community of West African States (ECOWAS) zone have been two major events in this regional integration (Hugon, 2003).

The West African regional policies have resulted in monetary stability, development of infrastructure and external economic liberalization. The region as a whole signed several free trade agreements with other partner countries, such as the Economic Partnership Agreements (EPA) between ECOWAS and the European Union. This external liberalization has strongly increased the competition of imports on domestic markets in the region. In the short run, this has contributed to a slight decrease in the share of local agriculture in the provision of agro-food products to the growing urban markets (Gret-Iram, 2008). In reaction, West African countries have revised their External Common Tariff (ECT) towards the definition of a list of "sensitive" products that need to be more carefully protected.

The regional integration dynamic has also provided an opportunity to define common agricultural policies (CAP) that have resulted in putting rural development issues as a priority on the political agenda.

### *National sectoral policies focusing on modern agriculture*

The Sahelian countries are very diverse and encompass a wide variety of national sectoral policies that are being implemented. However, most of those national policies have been shaped in the context of the domestic liberalization programmes that started in the late 1980s. Therefore, most of sectoral agricultural policies give priority to state withdrawal, to free market processes and to the promotion of commercial agriculture and agro-business. In that context, family agriculture has been undergoing a deep agrarian transition with very low support from governments (Engelhard, 2000; Losch, 2008). Except in some selected value chains (such as cotton, or irrigated rice), most of the national programmes offer relatively weak agricultural services, and rely more and more on private professional organization to manage collective actions. Poor access to seeds, to fertilizers, to credit, to capacity building and to reliable outlets are therefore key institutional constraints to the adaptation of crop–livestock systems to their changing environment (Duteurtre, Faye and Dieye, 2009).

In the context of high volatility of international prices, most West African countries decided to adopt specific "ad hoc" measures related to trade barriers, import taxes and domestic prices regulations in order to tackle food security. But the policy options that resulted from those "food crises" have revealed that consumers' interests were sometimes more important than those of smallholder producers in the policy decision processes (Corniaux *et al*., 2011).

### *Local policies: actors networks and international aid*

The third level of policy governance is related to local policies conducted at small-scale territorial levels. These have been strongly influenced by local environmental and economic conditions, traditional social structures and recent decentralization policies. Therefore, it is very difficult to generalize the wide diversity of situations encountered in the whole Sahel.

Local governance in the Sahel might, however, show a set of constant characteristics that refer to the importance of local networks dynamics, local rules for accessing natural resources, and international aid (Watts, 1987; Magrin, 2007; Touré, 2010). One of the striking issues for policy options in this context is the impact of development programmes on the empowerment of local stakeholders and on local governance. Food aid programmes, in particular, constitute crucial safety nets for mixed crop–livestock systems in the Sahel, but they might also result in de-structuring local policy networks and creating social inequities (Barret, 2003). Another issue of local governance is to evaluate to what extent local development projects might support local planning in order to foster the setting of market infrastructures, credit schemes, capacity building or agricultural services that fit the local development priorities (Magrin, 2007).

In this context of multiscale and multistakeholders' governance processes, each future policy option will need to be defined in coherence with the others. Greater participation of farmers' organizations in the governance process is also likely to increase the impact of those policy options on the adaptive capacity of rural communities, and on the resilience of the very diverse mixed crop–livestock production systems.

### *Technical dimension*

At the farmer scale, a number of biotechnical options might help to enhance adaptation capabilities and food security. We shall propose here some options organized in three categories: adapted information tools, agro-ecological intensification, and innovation in production systems.

#### *Adapted information tools to enhance anticipation*

To allow farmers, stakeholders and politics to anticipate and manage crisis and to adapt to short- and long-term changes, it is necessary to improve availability, circulation and quality of various kinds of information. In various domains such as resource availability (rainfall, vegetation, water, livestock population, etc.), marketing (food and livestock prices in markets), sanitary and disease status (livestock, crops, food, human, etc.), services and regulations, the lack, inaccuracy or irrelevance of information is a serious constraint. Much input has to be developed in that way. However, a number of information systems and early warning systems (resources, markets, health) have already been proposed, many of them using high technologies. But due to inappropriate forms of information to final stakeholders, high running costs, poor quality or relevance of indicators used, most of these information systems are poorly efficient. Whereas early warning systems for food security in cropping regions relying on sedentary people and some market information systems are today efficient, there is still a lack of an operational information system adapted to crop–livestock systems. Some efforts are in course through collaboration between FAO, CILSS countries and institutions, and show how important the participatory process is between all stakeholders in building an appropriate and operational information system where each of the partners can contribute and share knowledge and resources (Van Dijk 1997; Ickowicz *et al.,* 2005; Ancey *et al.,* 2009; Touré *et al.,* 2009; Wane, 2010).

#### *Agro-ecological intensification*

Another option at farm level to enhance adaptation capacities and food security in the Sahel is to improve production while preserving ecosystems and the environment. In the Sahel, ecosystems have a low productivity (low and irregular rainfall, poor soils) and are very sensitive to inappropriate management that leads to degradation of ecosystems and desertification. The new concepts of agro-ecology and ecological intensification (Cassman, 1999 in Bonny, 2011; Griffon, 2006) propose a change in paradigm for agriculture, trying to combine increase in food production together with better and sustainable functioning and management of ecosystems. For crop–livestock systems, the meaning and consequences of ecological intensification are investigated in current research[4]. Low level of intensification adjusted to seasonal and annual variability and ecosystem potential and services is combined with intensive use of local knowledge on natural resources and livestock needs, through straight links between social organization and animal production experts. Technical options for better integration of crop and livestock production to improve soil fertility and to reduce, through prevention practices, production losses due to diseases, pests and bad conservation of stocks, have been investigated in the last decades but need to be improved. Moreover, ecological intensification might also reduce GHG emissions, which in these types of livestock systems (livestock only grazing systems, rainfed mixed crop–livestock systems) are mainly due to poor feed diet with high fibre content. Indeed, the global impact of crop–livestock systems on the ecosystems and the environment are still debated owing to the lack of local accurate data (specific local emission factor for GHG depending on ruminant diet variability; actual volume of carbon sequestration in wide Sahelian rangelands), and there is a need for a better estimate of those impacts (carbon sequestration, biodiversity impacts, GHG emissions, water cycle).

*System innovation*

As described in the introduction of this paper, most of crop–livestock systems rely on the mobility of the livestock system for livestock grazing systems in arid and semi-arid zones and rainfed mixed crop–livestock systems and some of them for the irrigated mixed crop–livestock systems. Whereas mobility is nowadays recognized as a relevant adaptation to variable environment, changes due to economic, environmental and social factors at local and global levels induce rapid changes in livestock systems worldwide (Gibon and Ickowicz, 2010). Diversification of activities of livestock farmers in agricultural or non-agricultural work, change in mobility regimes (part of family and of the herd), reorganization of the labour force, change in livestock species composition of the herd, decrease or increase in specialization of production, reduced interactions between livestock and crop farmers are some of the main trends observed in rural areas in the Sahel (Vall, Dugué and Blanchard, 2006; Manoli *et al.*, 2010). These changes seem to be driven by food security goals at short- and mid-term time scales but there is no evidence that these trends are sustainable for human societies and ecosystems. At farm level, these innovative systems will have to respond to the double challenge of mitigating environmental impact and taking care of limited resources, leading to the need for better efficiency in resource use. But, at a more regional or national level, there is a real need to globally assess the impacts of these changes in terms of ecological, social and economic effects and to build and think

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[4] Agence Nationale pour la Recherche (France) research project “The interactions livestock – local development and the dynamics of the ecological intensification” – Mouve, 2011–2014

innovative systems through a participative approach among farmers, local and national policy-makers and scientists.

## CONCLUSION

Crop–livestock production systems in the Sahel have been adapting their practices and way of life for decades to various risks: climatic variability, economic risks and livestock diseases. To cope with shocks and crisis but also to support changes, they have developed various strategies based on the mobility of livestock and/or families, reorganization and diversification of activities, reciprocity and social networks. These strategies have allowed them to reproduce their societies through several major political events and droughts in the Sahel. Nowadays, climate change combined with other major factors (demographic growth, market globalization, decentralization, security issues) puts more pressure on their societies as their strategies might be not sufficient to deal with those global changes on their own and to preserve their food security. Present Sahelian policies oriented towards more regional and domestic economic liberalization leading to more competition for land and other resources are unfavourable for smallholders' crop-livestock systems. There is an important risk in that process that they will lose their adaptive capacities to changes and crisis, being more exposed to present risks (extreme climatic events, economic and market crises) and finally jeopardizing millions of people, millions of livestock and millions of hectares of natural resources.

In this paper, we have shown how marketing policies, land tenure and land-use management and regulations, investments in infrastructures and services are main priorities to enhance the capability of crop–livestock systems to adapt to the recent changes. Synergies between policy-makers, livestock experts and crop–livestock systems' farmers in the definition of strategies and policies at different levels (regional, national, local) are needed to define proper ways of development in this area. In the context of Sahelian countries, to respond to the growing demand in animal products, a combination of industrial or semi-industrial livestock systems together with smallholder livestock systems will allow the provision of more products, appreciatio of the value of large areas of rangeland resources and the preservation of livelihoods for nearly 60 percent of the Sahelian human population. Taking into account the rapid changes in global and regional markets and in demographic pressures on land, it is timely to define economic policies and land-use policies from the regional to the local levels and in a participatory multistakeholder approach to take into account national as well as local livestock development issues. These policies would have to consider, on one hand, how to enhance adaptation strategies of crop–livestock systems (mobility, diversification, access to infrastructures and services, education) that will allow the improvement of production, livelihoods and social status of millions of people who own millions of livestock and to optimize the use of huge amounts of natural resources of rangelands and crop by-products. On the other hand, these policies would have to offer opportunities for entrepreneurs to develop more intensive and complementary livestock systems (milk, meat) to value other local resources when available (agricultural products or by-products, water, arable land, etc.) in an affordable, economical and institutional context (price policies, import taxes, technical services, transport infrastructures, etc.).

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# Rice in Southeast Asia: facing risks and vulnerabilities to respond to climate change

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Rice is one of the most important staple foods for more than half of the world's population (IRRI, 2006) and influences the livelihoods and economies of several billion people. In 2010, approximately 154 million ha were harvested worldwide, of which 137 million ha (88 percent of the global rice harvested) were in Asia – of which 48 million ha (31 percent of the global rice harvested) were harvested in Southeast Asia alone (FAOSTAT, 2012) (Figure 1). The greatest levels of productivity are found for irrigated rice, which is the most intensified production system, where more than one crop is grown per year and yields are high – 12.5 tonnes/ha/year compared with 2.5 tonnes/ha/year for rainfed rice. Approximately 45 percent of the rice area in Southeast Asia is irrigated, with the largest areas being found in Indonesia, Viet Nam. Philippines and Thailand (Table 1) (Mutert and Fairhurst, 2002).

In Southeast Asia, where agriculture is a major source of livelihood, approximately 115 million ha of land are devoted to the production of rice, maize, oil palm, natural rubber and coconut (ADB, 2009). Rice has been feeding the region's population for well over 4 000 years and is the staple food of about 557 million people (Manzanilla *et al.*, 2011). In 2007, the average annual consumption per capita was about 197 kg (FAOSTAT, 2012) and provided 49 percent of the calories and 39 percent of the protein in the diet (FAOSTAT, 2012). Rice-growing methods have evolved through programmes such as Farmer Field Schools

**Table 1: Area (000 ha) under irrigated and rainfed lowland rice in Southeast Asia**

| Country | Irrigated | Rainfed |
|---|---|---|
| Cambodia | 154 | 1 124 |
| Indonesia | 6 154 | 4 015 |
| Lao PDR | 40 | 319 |
| Malaysia | 445 | 152 |
| Myanmar | 1 124 | 4 166 |
| Philippines | 2 334 | 1 304 |
| Thailand | 2 075 | 6 792 |
| Viet Nam | 3 687 | 1 955 |

*Source*: IRRI Rice facts 2002 in Mutert and Fairhurst (2002).

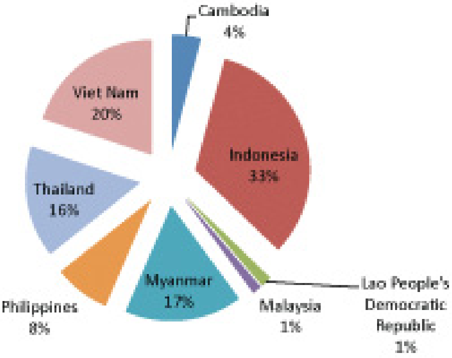

**Figure 1. Production of rice paddy in 2010**
*Source*: FAOSTAT (2012).

(FFS), pioneered in Southeast Asia, that were successful in addressing pest management issues. They have advanced along with the accumulation of knowledge and technology that the people of the region have acquired in the quest for progress. Such has been the role of rice in that quest that, throughout Southeast Asia today, rice is more than just food: it is the central subject of economic policy, a determinant of national objectives, and an important anchor in the maintenance of political stability.

## OVERALL CHALLENGES

The IPCC 4th Assessment Report (IPPC, 2007) states that Southeast Asia is expected to be seriously affected by the adverse impacts of climate change. Since most of its economy relies on agriculture and natural resources as primary income, climate change has been and will continue to be a critical factor affecting productivity in the region. In the last five years, there has been an increase in the number of floods and periods of drought, and some of the most devastating cyclones, and water, soil and land resources are continuing to decline. In Indonesia, the Philippines, Thailand and Viet Nam, the annual mean temperatures are projected to rise by 4.8 °C by 2100, and the global mean sea level will increase by 70 cm during the same period (ADB, 2009). In Southeast Asia as a whole, small changes in the annual rainfall are foreseen to continue to 2040 (Cruz *et al.,* 2007) and there will be an increase in the occurrence of severe weather including heatwaves and precipitation events. Increases in tropical cyclone intensities by 10–20 percent are anticipated, and temperatures are projected to continue to increase by about 0.7–0.9 °C (Cruz *et al*., 2007). In the last few decades, sea levels have risen by 1–3 mm/year, marginally higher than the global average (ADB, 2009).

Rice production systems of the region have over recent years become increasingly threatened by the effects of climate change (Masutomi *et al.,* 2009), as a large portion of the rice-growing areas are located in especially vulnerable regions. A number of countries have, in fact, begun to see a gradual stagnation in production levels brought about by major production constraints for rice in Southeast Asia (Annex 1). Changes in temperature regimes greatly influence not only the growth duration, but also the growth pattern and the productivity of rice crops. The critical temperatures for the development of the rice plant at different growth phases are shown in Table 2. A decrease of 10 percent in rice yield has been found to be associated with every 1 °C increase in temperature (ADB, 2009), while Peng *et al.* (2004) reported that the yield of dry-season rice crops in the Philippines decreased by as much as 15 percent for each 1 °C increase in the growing season mean temperature.

These temperature and aggravating climate change effects may cause a decline in the world rice production (Furuya and Koyama, 2005; Li and Wassmann, 2011), and have already proven to have negative effects on agricultural production and the socio-economic conditions of farmers. For example, in Indonesia, the total damaged area and production losses because of flooding were estimated to be 268 823 ha and 1 344 million tonnes, respectively. With an average yield of 5.0 tonnes/ha, economic loss was estimated at about USD 353.7 million/year affecting 4.4 million farm households (Wassmann *et al.,* 2011).

Predictions show that there may be a further decrease of 3.8 percent in rice production in Southeast Asia under the climates of this century, because of water scarcity and

**Table 2: Critical temperatures for the development of the rice plant at different growth stages**

| Growth stages | Critical temperature (°C) | | |
|---|---|---|---|
| | Low | High | Optimum |
| Germination | 16–19 | 45 | 18–40 |
| Seedling emergence | 12 | 35 | 25–30 |
| Rooting | 16 | 35 | 25–28 |
| Leaf elongation | 7–12 | 45 | 31 |
| Tillering | 9–16 | 33 | 25–31 |
| Initiation of panicle primordial | 15 | - | - |
| Panicle differentiation | 15–20 | 30 | - |
| Anthesis | 22 | 35–36 | 30–33 |
| Ripening | 12–18 | >30 | 20–29 |

*Source*: FAO (2005).

increased temperatures, and in spite of $CO_2$ fertilization (Murdiyarso, 2000). By 2100, Indonesia, the Philippines, Thailand and Viet Nam are projected to experience a potential fall of about 50 percent in rice yield, assuming no adaptation and no technical improvement. The rice yield decline would range from 34 percent in Indonesia to 75 percent in the Philippines (ADB, 2009).

## THREATS TO RICE PRODUCTION

### Drought

Current rice production systems rely on an ample water supply and thus are more vulnerable to drought stress. Drought is the most important limiting factor for rice production and is becoming an increasingly severe problem. Since early November 2009, rainfall has been consistently below the long-term average in Southeast Asia, particularly causing drought in Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam. It is estimated that 50 percent of the world's rice production is affected to a greater or lesser extent by drought (Bouman *et al.,* 2005).

Drought stress is severely damaging during reproductive stages of the rice crop, especially during flowering, although drought in other stages can also lead to significant yield reductions (Liu *et al.,* 2006). Drought is the most serious constraint to rice production since most of the farmers' preferred rice varieties are susceptible to drought stress (Serraj *et al.,* 2009).

Average yield reduction in rainfed, drought-prone areas has been found to range from 17 percent to 40 percent in severe drought years, leading to huge production losses and chronic food scarcity (Greenbio, 2011). In 1997/1998, droughts caused massive crop failures, water shortages and forest fires in various parts of Indonesia, Lao PDR and the Philippines. More recently, in 2010, the level of the Mekong River (that flows through Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam, covering some 4 350 km and affecting the livelihoods of more than 60 million people living along the riversides) reached its lowest water levels in 20 years. In the Philippines, El Niño-induced climate variability regularly results in: (a) late onset of the rainy season; (b) early termination of the rainy season; (c) weak monsoon events characterized by isolated heavy rainfall events of short duration; and (d) weak tropical cyclone activity characterized by less intense cyclones (Lansigan, de los Santos and Coladilla, 2000). In 2009, the Philippines suffered from an El Niño-induced drought, drying up watercourses and irrigation systems in some of the most productive rice areas in Luzon, leaving parched and cracked paddies in its wake as it extended into the following year. By mid-February 2010, the Philippine Department of Agriculture had announced that rice production in the country decreased by some 3.31 percent from the levels realized in 2008 (a loss of approximately 494 700 tonnes from 2009 to 2010 [FAOSTAT, 2012]).

**Case Study: Philippines**

Rice is the staple food for about 89% of the population of the Philippines and is the source of income and employment for about 12 million farmers and family members (FAO, 2007a). It has been traditionally grown in six major regions and is predominately produced on small landholdings that average 1.7 ha (Estudillo and Otsuka, 2006).

The Philippines is a centre of diversity of rice. Extensive traditional varieties exist, consisting of farmers' varieties adapted to varied agro-ecological zones (e.g. lowland irrigated paddy, lowland rainfed, upland, saline, and cool elevated areas [Estudillo and Otsuka, 2006]). There are, to date, a total of over 5 500 collected and documented traditional varieties of rice in the country.

However, with the increase in climate change events, farmers are finding it more difficult to maintain rice production levels. They can no longer depend on the seasonal rainfall to irrigate their paddy fields and therefore farmers have to pump groundwater onto the field (about 5 000 litres are needed for 1 kg of rice). However, this is having financial implications for the farmers. They now need to buy diesel in order to run the pump (per hour a farmer in the Philippines will use about 8 litres of diesel; on average to fill a paddy field the pump is used for 2–4 hours).

Farmers in the Philippines are adopting new strategies in order to try and combat these issues. They have implemented alternate wetting and drying technologies, developed by IRRI, which improved the use of irrigation water and increased productivity. This reduced the methane emissions by almost 50% compared with the production of rice under continuous flooding. The farmers were able to increase their income while decreasing greenhouse gas emissions on the whole (IFPRI, 2009).

## Salinity

Rice is considered to be moderately sensitive to salinity (IRRI, 1997). The symptoms of salt injury in rice are stunted growth, rolling of leaves, white tips, drying of older leaves and grain sterility. Soil salinity limits the rice plant's growth and development, resulting in yield losses of more than 50 percent (Zeng and Shanon, 2000). Sensitivity of rice to salinity stress varies with the growth stage. Though salinity affects all stages of the growth and development of the rice plant, when the rice is at the young seedling stage it becomes even more sensitive to salinity (Shereen *et al.,* 2005; Deepa Sankar, Saleh and Selvaraj, 2011). Existing guidelines (Maas and Grattan, 1999; Hanson, Grattan and Fulton, 1999) indicate that rice yields are reduced by 12 percent for every unit of salinity (dS/m[1]).

In the humid regions of Southeast Asia there are many hectares that are technically appropriate for rice production but are left uncultivated or are grown with very low yields because of salinity and problem soils. Low water levels in Viet Nam's Mekong River Delta, the country's rice bowl, have resulted in an inward flow of salt water, increasing the salinity in the river water and endangering rice paddies. In addition, in the rainfed rice fields

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[1] Unit of measurement for salinity- dS/m= deciSiemens per metre

of northeastern Thailand, salinity affects about 3 million ha, representing 17 percent of the surface area (Clermont-Dauphin *et al.*, 2010).

## Rising sea levels

Experts predict that the sea levels will rise by about one metre by the end of the twenty-first century as a result of global warming (IPCC, 2001). As heat is trapped, it accumulates in the earth's atmosphere, meaning that water from melting glaciers and polar ice caps will gradually swell the banks of the Mekong and Red Rivers. This will in time affect the entire hydrology of myriad watercourses, including changes in sediment discharge and shoreline gradients – the very dynamics that form the core of all rice production in Viet Nam. Higher sea levels will impede gravitational river discharges and deccelerate tides further inland. More than 50 percent of Viet Nam's rice production (Minh and Kawaguchi, 2002) is grown in the Mekong Delta, with another 17 percent in the Red River Delta (IRRI, 2008).

In combination with heavy monsoon rainfall, rising sea levels create serious water-logging and prolonged stagnant floods in major rice-growing, lowlying mega-deltas in Southeast Asia, for example in the Mekong Delta and Red River Delta in Viet Nam and the Irrawaddy in Myanmar. Rising sea levels may deteriorate rice production in the deltas since only a few low-yielding rice varieties have evolved to withstand such conditions (Wassman *et al.,* 2009), which means that under extreme sea level cases, countries such as Viet Nam find themselves having to alter their trade from exporters to importers (Chen, McCarl and Chang, 2012) to maintain food security.

**Case Study: Viet Nam**

Viet Nam is one of the centres of origin of rice cultivation. Rice occupies 74 percent of Viet Nam's 5.7 million ha of arable land (IRRI, 2008). Rice production is dominated by small, irrigated farms based around the Mekong River Delta in the south (52 percent) and the Red River Delta in the north (18 percent). In commercial farming in Viet Nam, both seasonal and semi-permanent adoption of climate-resilient rice varieties is practised (Snidvongs, 2006). The use of short cycle rice varieties allows farmers to produce two cycles of rainfed rice within the seven months of rainy seasons in the Mekong River Delta.

Climate change is increasing sea water levels, brought about by higher global temperatures, which will have significant negative consequences. If continued growth of greenhouse gas emissions and associated global warming continue up to 10.8 percent of the Viet Nam area (most of this impact is in the Mekong and Red River Deltas) would be impacted by a 1 m sea level rise (Dasgupta *et al.*, 2007). Estimates state that sea levels are expected to rise up to 33 cm by 2050 (IFPRI, 2010a). This is placing huge stress on the populations that live along the lowlying delta.

FAO-IAEA has collaborated with agricultural research institutes in Viet Nam to develop high-yielding rice varieties with good levels of tolerance to salinity such as VND 95-20 and VND 99-3 for planting in saline-affected soils in the Mekong River Delta (FAO, undated).

## Submergence

Along with rising sea levels, more frequent and intense tropical storms brought about by the shifting of La Nina will undoubtedly cause uncontrolled flooding throughout Southeast Asia. The region's coastlines are likewise fringed with rice production systems that receive heavy monsoon rainfall, often coinciding with strong sea disturbances and high tides. With the combined high rainfall and high tides, rice crops in coastal areas experience submergence with moderately saline water during early crop growth (Wassman *et al.,* 2009).

Submergence is increasingly becoming a major production constraint affecting about 15–20 million ha of rice fields in South and Southeast Asia and causing a loss of up to USD 1 billion every year. During 2004, Thailand suffered from a tsunami that killed a total of 8 221 people. In 2010, flooding killed 231 people, and caused economic damage of 32–54 billion baht according to the Department of Disaster Prevention and Mitigation, Ministry of Interior. It saw a reduction in production quantity, from 32 116 100 tonnes in 2009 to 31 597 200 tonnes in 2010, a loss of 518 900 tonnes in only one year. While rice thrives in wet conditions, it cannot survive when submerged under water for long time periods. Stagnant flooding affects rice crops at any stage of growth although submergence intolerance at the vegetative stage is the most common problem (Mackill *et al.,* 2010).

Submergence is also causing increasing negative effects for rainfed rice areas, specifically in areas where resource-poor farmers rely on the annual rain precipitation for their crops. More than 100 million people in South and Southeast Asia depend on these systems for their livelihood (Manzanilla *et al.,* 2011).

The destruction caused by recent typhoons in Southeast Asia clearly demonstrates just how vulnerable the region's rice systems are to typhoons and floods. In late 2011, a string of typhoons tore across Southeast Asia, causing floods that destroyed around 12.5 percent of Thailand's rice farmland, along with 12 percent in Cambodia, 6 percent in the Philippines, 7.5 percent in Lao PDR, and 0.4 percent in Viet Nam. By year-end, the floods had pared Thailand's rough-rice production by around six million tonnes while the Philippines lost some 600 000 tonnes of milled rice to the floods and strong winds brought on by the typhoons (GIEWS, 2012).

## Socio-economic factors

Climate change presents an additional burden on the world's agricultural and natural resources, which are already coping with the growing food demand driven by population growth and higher income in developing countries (Wassmann *et al.,* 2011). This is reflected in the escalating volumes of rice imported by nations that regularly experience production deficits. Indonesia, Malaysia and the Philippines have begun to develop an untenable dependence on imported rice to ensure sufficient national stocks. In the 1990s, rice importation for these three countries increased by around 1.5 million tonnes over the annual average registered during the previous decade. By 2000, rice imports undertaken by Indonesia, Malaysia and the Philippines had risen to some 6.5 million tonnes (Mutert and Fairhurst, 2002). In 2010, the Philippines alone had to import 2.45 million tonnes of rice to address domestic requirements (IRRI, 2010).

Global imports constitute less than 10 percent of all rice consumption, which partly explains why international rice prices have always been more volatile than other prices and much more volatile than domestic rice prices (IFPRI, 2010b). Most rice produced by farmers across the globe is consumed domestically, and the marketable surplus is therefore small. Moreover, the rice export market is highly concentrated, with the top five exporting nations – Thailand, India, Viet Nam, the United States of America and China – accounting for 83 percent of the rice traded in global markets (FAO, 2002a). Because of this, any change in production among exporting countries weighs heavily on available global supplies, as demonstrated by the crisis in 2007/2008.

This growing need to import rice is not only due to the effects of climate change. Small-scale farmers (family farmers) are finding it hard to buy the best seeds, as well as appropriate resources to irrigate and fertilize their land adequately, owing to the increase in prices. Moreover, these small-scale farmers, who are often in charge of rainfed rice production, are the most vulnerable – as in the case of Cambodia, where 80 percent of the farmers grow rice, of which 60 percent of the rice is for family subsistence. In addition, coupled with the increase in urbanization and industrialization, the need to increase food supply (as population increases by 2 percent annually[2] [ADB, 2009] the demand for rice within Southeast Asia is projected to increase by 11 percent by 2015 [IRRI, 2006]) is becoming progressively more important.

Urbanization is another issue. The areas that are under the most productive and fertile irrigated rice lands are located in areas of high population density (Mutert and Fairhurst, 2002). In the Philippines, for example, much of the land is mountainous and made up of small islands, therefore unsuitable for rice production. With the increase in population and a need for more urban areas, the area available for paddies is decreasing. Some 50 percent of irrigated cropland in the Philippines has already been lost to urban development. In Thailand, losses are estimated at 32 $km^2$ of farmland to the urban sprawl annually, while in Java, Indonesia, farmers lose some 200 $km^2$ of cropland a year to industry and human settlements (Sundquist, 2007). With the continued increase in urbanization, the loss of agricultural lands, especially paddy lands, is predicted to increase rapidly in the next few years.

## RESPONSES

### Adaptation

Rice production has always been impacted by different stresses, including environmental – and has looked for ways to manage these. Climate change adaptation requires more than simply maintaining the current level of performance from the rice production sector, but rather developing a set of responses that allow the sector to improve performance under the changing conditions climate change implies.

Adaptation to climate change in rice production systems is complex and must involve a range of environmental, social and economic factors. It must also involve creative financial and technological factors such as better understanding and application of indigenous knowledge and coping strategies.

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[2] Compared with the 1.4 percent global annual increase (ADB, 2009).

**Example of an adaptation solution: Terrace system**

The terrace system is a typical product of the ponding technique that allows cultivation even on steep slopes. This technique is useful not only in the prevention of soil erosion and landslides but also for its capacity for flood control.

In the Ifugao rice terraces in the Philippines water management and conservation are being carried out through the use of micro-watersheds in highland areas. The permanent presence of water on rice fields furthermore generates water percolation and groundwater recharge, which are often beneficial for other water uses. This provides the farmers with constant water (from the forest clad mountain tops and creating stone terraces and ponds), therefore allowing them to adapt to the climatic variations. One major advantage of water ponding in rice cultivation is that it prevents weed development, thereby avoiding the use of herbicides or reducing the amount of labour required (FAO, 2004b)

However, rice production is a complex "biological factory". Farmers work in a system of great unreliability. Heavy rainfalls, droughts and temperature rises are already affecting the production and quality of products. A complicated interaction exists between the many parameters of production. This means that the effect of "controlled actions" depends on factors that are more or less out of the control of the individual farmer. Nevertheless, farmers have developed practices and strategies to cope with uncertainties and continuously create more resistant and resilient production systems. Examples include improved water management and irrigation, constraining or moving the growing period, or changing the crop rotation.

There are a range of options that can be used to adapt to the effects of climate change. These include:

- **Selection of appropriate planting date.** The planting date can have a dramatic effect on the development and yield of the crop. As temperature varies, the aims would be to try and select the right date for crop establishment in order to allow for the reproductive and grain filling phases of rice to take place during the months with a lower temperature (FAO, 2004a).
- Use of **traditional varieties** with high resilience and **breeding of new varieties** with higher temperature tolerance, resistance to salinity, drought and floods. A report conducted by the Australian Centre for International Agricultural Research has demonstrated that the average annual value is equivalent to USD127/ha (in 2009 values) across the average rice area in southern Viet Nam of over 4.2 million ha/year since 1985. This is significantly higher than the average value per hectare for the Philippines

**Example of an adaptation solution: Scuba Rice**
IRRI, funded by DFID, has identified a waterproofing gene called Sub1A in support of building crop resilience to climate change (DFID, 2011). This gene allows rice to survive while being completely submerged for two weeks. It survives by extending its leaves and stems above the water's surface to escape drowning.

Scuba rice has already been disseminated across ten Asian countries (Cambodia, Indonesia, Lao PDR, Myanmar, the Philippines, Thailand, Viet Nam, Nepal, Bangladesh and India). In Bangladesh, it produced high yields and minimized crop loss due to floods (95% of scuba plants recovered after flooding compared with just 12% for a traditional variety).

**Example of an adaptation solution: Symbiotic technology**
Recent research shows that using fungal endophytes (fungi that live within a rice plant without causing it harm) reduces water consumption by 20–30% and significantly increases the growth and development of seedlings in the absence of stress. The findings indicate that fungal endophytes enhance the stress tolerance in rice plants via symbiosis with Class 2 endophytes, and suggest that symbiotic technology may be useful to combat the impacts of climate change (Redman *et al.,* 2011).

(USD52/ha) and Indonesia (USD76/ha) (Brennan and Malabayabas, 2011). In addition, **hybrid rice**, where two varieties are crossed, for example a high-yielding variety that is not salt-tolerant with some land races that are salt-tolerant (IRRI-bred variety, labelled as IR63307-4B-4-3), can be used to increase yields (up to 30 percent more yield can be generated using a commercial hybrid rice compared with a high-yielding inbred rice variety). In addition, appropriate infrastructure needs to be in place and research needs to be undertaken into **hydroponic seed production technologies**, **aerobic rice varieties** and **rainwater harvesting** for production systems situated in upland and rainfed areas.

- **Site-specific nutrient management (SSNM):** This approach enables rice farmers to tailor nutrient management to the specific conditions of their fields, and provides a framework for nutrient best management practices for rice. It is a sophisticated knowledge system focused on double and triple rice monocropping (FAO, 2011). A study conducted in the Mekong Delta showed that by using SSNM an increase in grain yield of about 0.5 tonnes/ha was obtained (Hach and Tan, 2007).
- **Alteration of farm management practices**: Farmers in different countries split their rice plots into two using different management approaches to address uncertainty in rainfall (such as in Cmbodia). Half of the rice plot uses conventional wet-paddy rice techniques (that can survive the heavy rains) and the other half uses a drought-resistant, less water-intensive cultivation technique called "system of rice intensification" (Resurreccion, Sajor and Fajber. 2008).

**System of Rice Intensification**

SRI has been explicitly conceived of and presented not as a technology but rather as a methodology based on a set of ideas and insights formulated as principles that are to be translated into specific practices, which seek to create a more favorable growing environment for irrigated rice plants (Uphoff, undated). The methodology is presented to farmers as a set of practices of techniques that simply need to be adopted. The practices include (Ciifad, 2002):

- seedlings transplanted at a very young stage usually just 8–12 days old, with just two small leaves;
- transplanting of seedling carefully and quickly in order to have minimum trauma occurring in the roots;
- seedling are planted singly, only one seedling per hill, rather than 3–4 together, this avoids root competition;
- seedlings are planted with wide spaces between each seedling, so as to encourage a greater root and canopy growth;
- plant in a square grid pattern (i.e. 25x25 cm or wider);
- plant in good quality soil, and keep the soil well drained (rather that continually flooded during the vegetative growth stage); and
- weeding should be carried out at the early stages and should be frequent.

- **System of Rice Intensification (SRI):** This is an agro-ecological methodology aimed at increasing the yield of the rice produced in irrigated farming by changing the management of plants, soil, water and nutrients. Compared with common rice production practices, SRI has numerous benefits as it is an example of options available to farmers and nations to promote community-led agricultural growth, while managing soil and water resources more sustainably and even enhancing their future productivity (Africare, Oxfam America, WWF-ICRISAT Project, 2010). Successful applications of SRI have shown that farmers are able to increase their paddy yields by 50–100 percent while using fewer inputs, in particular water (farmers were able to reduce their water requirements by about 25–50 percent) (Uphoff, 2007). The average increase in income from SRI in eight countries (Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri Lanka and Viet Nam) has been shown to be around 68 percent, with yield increases of 17–105 percent and decreases in water requirement between 24 percent and 50 percent (Africare, Oxfam America, WWF-ICRISAT Project, 2010). With the increased impacts of climate change, increasing variability of rainfall, and the growing competition for water and land, SRI offers a new opportunity for increasing the production value per drop of water and for reducing agricultural water demand (The World Bank, 2008). As rice cultivated under SRI grows with stronger stalks and longer roots, it is more resistant to episodes of drought, waterlogging, storm and typhoons.
- **Crop rotation:** Rotation of crops that have their most drought-sensitive phase in different phases of the growing season may prove a valuable adaptation to limited water resources. In the Philippines, in recent years, fish or ducks have been raised with rice,

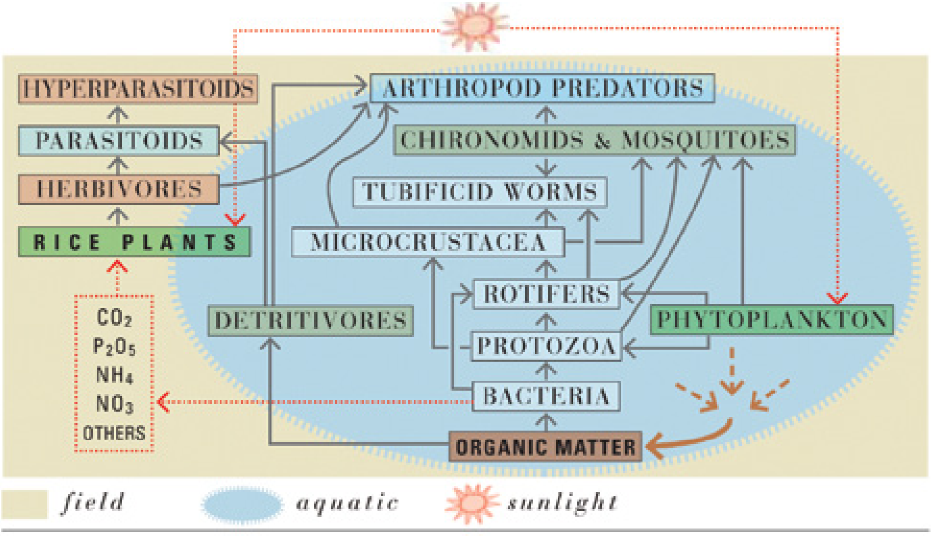

**Figure 2. Food webs in a rice field**
*Source*: FAO (2009).

as well as legumes such as mungbean (*Vigna radiata*), groundnut (*Arachis hypogaea*) and soybean (*Glycine max*) after two rice croppings (FAO, 2007a).

- **Rice and integrated pest management (IPM):** Flooded rice agro-ecosystems have evolved under human management for more than 5 000 years – or more than 50 000 generations of plant feeders (herbivores). When the ecosystem is not disrupted, these insects are part of a complex food web (Figure 2) that converts sunlight and soil organic matter into energy that supports many species of insects and spiders in every rice field: in soil, under and on top of water, and on or around plants including rice. These food webs fulfil the ecosystem function of naturally occurring biological pest control in annual crop systems such as rice. Their capability of keeping the system in balance varies as the predators multiply or leave to other fields in their search for larger populations of food (pests). Making the rice field ecosystem healthier means enhancing this ecosystem function by protecting the role of natural enemies to feed on pests. If the balance is broken by improper use of pesticides, the pests may prevail on natural enemies causing outbreaks (Allara *et al.*, 2012).

## Mitigation

Rice production, especially from flooded rice soils, is a large source of atmospheric methane, therefore a large contributor to global warming (FAO, 2004a). According to the IPCC (2007), estimates of the global emission rate from paddy fields (where $CH_4$ is predominant) are 60 Tg/year. Under anaerobic conditions of submerged soils of flooded rice fields, the methane that is produced predominately escapes from the soil into the atmosphere via gas spaces that are found in the rice roots and stems, and the remainder of the methane bubbles up from the soil and/or disperses slowly through the soil and overlying flood water (Figure 3).

In the same way that the efforts to ensure the ability of Southeast Asia's rice production systems to adapt are made more difficult by climate change, programmes that mitigate the impact of rice production on the natural resource base must be both broad and detailed. Mitigation systems must be developed that offer inputs that will provide farmers with affordable access to necessary technologies and technical assistance.

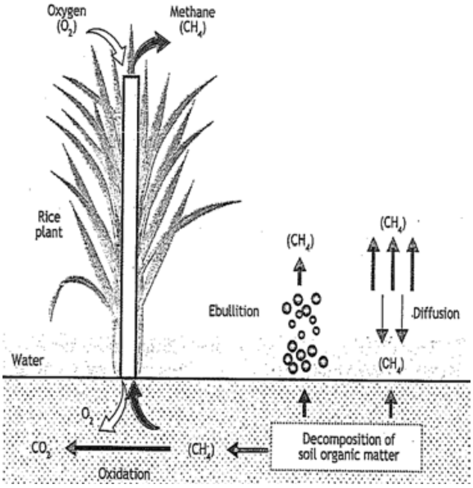

**Figure 3. Dispersion of methane**
*Source*: Maclean *et al.* (2002) cited in FAO (undated).

- **Flood irrigation** is often an inexpensive method depending on the access to the water resources. If the fields are completely even then it is possible to practise a reasonable irrigation, but this is not always the case. Hence, there is a high risk of loss of water and nutrients to the subsoil and groundwater. Furthermore, flooding techniques involve a high risk of $CH_4$ emissions. This is particularly evident in rice production, where the warm and waterlogged rice fields provide an optimal environment for $CH_4$ production. Rice production is responsible for 50 to 1 000 million tonnes $CH_4$/year and is probably the largest of the human-induced sources of this greenhouse gas (GHG) (FAO, 2007b). Research has shown that it is possible to reduce $CH_4$ emissions from rice production. In 2006, Jondee *et al.* discussed how, in Thailand, they changed the breeding programme for drought-prone rainfed lowland rice in order to increase tolerance to drought. In addition, a study conducted in China, indicated that water management by flooding with mid-season drainage and frequent waterlogging without the use of organic amendments is an effective option for mitigating the combined climatic impacts from $CH_4$ and $N_2O$ in paddy rice production (Zou *et al.,* 2005).
- **Intermittent irrigation or alternating dry-wet irrigation** could reduce emissions from rice-fields, while the transfer and adoption of a rice integrated crop management approach (e.g. the Australian RiceCheck) would increase the efficiency of nitrogen fertilizer in rice production, thus reducing $N_2O$ emissions (FAO, 2007c). Performing mid-season drainage and intermittent irrigation reduces the methane levels by about 50 percent.
- **Zero- or no-tillage and soil conservation** generate higher yields, reduce production costs and lessen erosion and land degradation. In addition, they improve environmental quality as they emit less GHG (therefore reducing the air pollution) through decreasing the use of diesel fuel and non-burning of rice residues (Adhikari *et al.,* 2007).
- **Rice residues:** On average after the rice is harvested and dehusked, rice straw and rice husk remain and are commonly re-incorporated into the soil or burned, which causes $CH_4$ and soot to be released into the atmosphere. Charring – or partly burning – rice residues and adding the obtained black carbon or "bio-char" to paddy fields instead of

incorporating untreated harvest residues may reduce field $CH_4$ by about 80 percent (IRRI, no date).

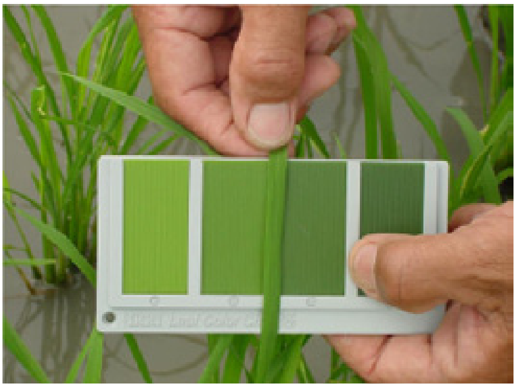

Figure 4. Leaf colour chart

- **Urea deep placement (UDP):** Deep placement of fertilizer has been recognized as a method to increase fertilizer use efficiency. It involves the placement of 1–3 g of urea granules at a soil depth of about 7–10 cm shortly after the paddy is transplanted. UDP doubles the percentage of nitrogen that is absorbed by the plant, reduces nitrogen that is lost in the air and to surface water runoff (as most of it remains in the soil close to the plant roots where it is better absorbed) and has produced an average yield increase of 18 percent in farmers' fields (FAO, 2011). The UDP technology increased paddy yield by 900–1 100 kg/ha (depending on the cropping season), and reduced urea use by 78–150 kg urea/ha. The net return to farmers of using UDP versus broadcasting urea averages about USD 188/ha (IFDC, 2004–2005; Roy and Groot, 2009).
- **Leaf colour charts:** This is a four-panel leaf colour chart (LCC), developed for rice cultivation in Asia, that corresponds to actual colours of rice leaves (Figure 4). The LCC consists of plastic panels, each with distinctly different shades of green – ranging from yellowish-green to dark green. The LCCs can be used by farmers in the field to determine how much nitrogen fertilizer is needed for efficient use, and to maximize rice yields (Witt *et al.,* 2005). It can be used for real-time N management and synchronizing N application with crop demand to reduce GHG emissions.

## Coping with change:

FFS is a form of adult education, which evolved from the concept that farmers learn optimally from field observation and experimentation. Unlike traditional approaches, it brings together concepts and methods that aim to help farmers produce crops more efficiently. Developed to help farmers tailor their IPM practices to diverse and dynamic ecological conditions (FAO, 2004c), it is an example of how farmers can adapt to and mitigate climate change through the ability to select, adapt and apply knowledge-intensive methods that are productive, profitable and sustainable.

FFS enables groups of farmers, through a participatory platform, to improve decision-making and stimulate local innovation by learning-by-doing. It has a strong emphasis on the development of human resources that brings about tremendous changes. It is a vehicle for knowledge and skill generation and has a proven track record of farmer empowerment at community level in Southeast Asia. Farmers increase their control over technologies, markets, relevant agricultural policies and their agro-ecosystems (FAO, 2002b).

Since the 1990s, FFS in the Philippines, through the IPM national programme (KASAKALIKASAN), introduced sustainable agricultural strategies that increased yields (Table 3) and provided positive profit to small subsistence farmers. In Indonesia, the FFS programme allowed farmers to considerably reduce the levels of insecticide and pesticides uses (Figure 5). In Cambodia, where use of hazardous class Ia and Ib insecticides is high, training enabled farmers to reduce pesticide volume in rice by 64 percent and to select relatively less hazardous compounds. FFS farmers were better aware of pesticide-related health risks than non-FFS farmers (FAO, 2004c). The FFS approach has also been used in Thailand, where a decrease of 60 percent in the use of insecticides and moluscicides in rice was shown in the season after training, and an increase in knowledge about pests and natural enemies.

**Table 3: Yield per hectare of rice, before and after FFS**

| | Yield (kg) | |
|---|---|---|
| | Before FFS | After FFS |
| **Wet Season** | 3 903 | 4 451 |
| **Dry Season** | 4 010 | 4 435 |

*Source*: FAO (2005).

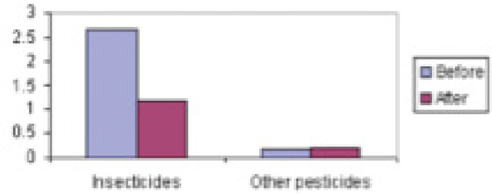

**Figure 5. Mean pesticide applications per field, before and after training**
*Source*: FAO (2004c).

The success of IPM FFSs has opened up a new approach to the development of sustainable, small-scale agricultural systems that can adapt to various kinds of changes including climate change. This will enhance agricultural productivity and resilience in the face of new climatic stresses.

## CONCLUSIONS

Rice production in Southeast Asia is highly vulnerable to climate change. As described in this paper, rice production simultaneously contributes to global climate change and is affected by it. However, there is a wide range of adaptation measures already being applied, and many examples of the potential that rice production has in contributing to the reduction of GHG emissions globally. In Southeast Asia this issue is of particular relevance owing to the importance of rice to the national food security, economy and livelihoods, and also because of the intensity of the impacts of climate change in the region. Adaptation and mitigation in rice production systems both have important roles to play. Farmers will need to have access to a genetically diverse range of improved crop varieties that are resilient to climate change and suited to a variety of ecosystem and farming practices. Adaptation will allow farmers to cope with climatic events, while mitigation practices will contribute to global reduction of GHG emissions from rice production.

Planning, policy and farm practices must be based on actual knowledge of systems that are already in place, but with emphasis on new adjustments to make them function with much greater efficiency in the future. Improved knowledge and technology concerning efficient use of inputs and research on stress-tolerant species need to be developed to allow farmers to increase the value of both the primary product of their enterprise as well as its by-products. Quality farmer education (such as through FFS) plays an important role in addressing sustainable livelihoods and in meeting the need to provide food for all, raising rural incomes, reducing poverty and sustainably managing the environment and natural resources.

An increased focus on traditional knowledge that includes the integration of research into adaptive capacity within farming systems is also needed in order to create resilience to the changing climate. In each country attention must be given to means of involving every relevant institution – public and private – in the process of reducing GHG emissions, renewing soil and water resources, and repairing the ecosystem.

Appropriate agricultural management practices are critical at the field level. However, a supportive policy, planning and institutional environment is also essential. Therefore, policy support to rice research and development to introduce and transfer appropriate and efficient technologies are vital to better understand the role of rice cultivation in climate change. In addition, it enables farmers to improve their production practices while adapting to the severe challenges to their food security posed by climate change. Increased support is also needed for the collection, conservation and utilization of plant genetic resources, as well as a need for funding to revitalize public plant breeding programmes even as the links between formal and farmer-saved seed systems are strengthened through appropriate policies, and efforts are undertaken to encourage the establishment of local seed enterprises. More work should be done to better understand the role of introducing other grain crops, legumes and pastures into the rotations and evaluating the benefits and trade-off of changing from monoculture of rice (at species and variety level) to more diverse systems that use biodiversity to improve adaptation, mitigation and food security. The achievement of climate resilience in Southeast Asia's rice production systems will depend on suitable policies that will govern the regulation of the seed sector in order to guarantee farmers' access to quality seeds (including the affordability and availability of a wide range of varietal material).

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## Annex 1: Main production constraints for rice in Southeast Asia

| CONSTRAINT | CAMBODIA | INDONESIA | LAO PDR | MALAYSIA | MYANMAR | PHILIPPINES | THAILAND | VIET NAM |
|---|---|---|---|---|---|---|---|---|
| Low soil fertility |  |  | Sand soils |  |  | 50% problem soils | >75% rice lands |  |
| Soil acidity |  |  |  |  |  |  | Acid sulphate soils | Acid sulphate soils |
| Salinity |  |  |  | Sea water intrusion | Sea water intrusion |  | NE and S coast | Coastal areas |
| Drought |  |  |  | Rainfed rice systems | Rainfed rice systems |  |  |  |
| Flooding | Low lying areas |  | Mekong River |  |  | Typhoons | In RLLR | Rainfed areas |
| Low temperatures |  |  |  |  |  |  | Upland in North, Irrigated in North and NE | North Viet Nam |
| Pests and diseases | Stemborer, gall midge | BPH, stemborer, BLB, blast, RTV |  | BPH, stemborer, blast, GLV, RTV |  | RTV, BLB, blast, GLH, stemborer | BLB, blast, BPH, stemborer | BPH, stemborer, leaf rolle, blast, BLB, brown spot |
| Weeds |  |  |  | Direct seeded rice |  | Direct seeded rice | Direct seeded rice | Direct seeded rice |
| Land fragmentation |  |  | Small farm size |  |  |  |  | Small farm size |
| Land security | Land mines |  |  |  |  |  |  |  |
| Rural poverty |  |  |  |  |  |  |  |  |
| Labor scarcity |  | In agriculture production areas |  |  |  |  |  |  |
| High input costs | Fertilizers |  | Fertilizers |  | Fertilizers | Fertilizers | Fertilizers | Fertilizers |
| Input scarcity | Infrastructure, credit, seed, fertilizers, agrochemicals | Lack of quality fertilizers | Infrastructure, credit, seed, fertilizers, agrochemicals |  | Infrastructure, credit, seed, fertilizers, agrochemicals |  |  | Infrastructure, credit, seed, fertilizers, agrochemicals |
| Rice price policy |  |  | Low price | Low price |  | Price policy |  |  |
| Ineffective extension |  |  |  |  |  |  |  |  |
| Land loss |  | Urban sprawl | Erosion |  |  |  |  |  |
| Others |  | New technology required | Preference for glutinous rice |  | Limited market opportunity |  |  |  |

BLB = bacterial leaf blight; BPH = brown planthopper; GLH = green leafhopper; GLV = green leaf virus; RLLR = rainfed lowland; RTV = rice tungro virus.
*Source*: Mutert and Fairhurst, as modified after IRRI Rice Facts, 2002.

# Country presentations

# Perspectives on risk management as climate change adaptation measure in Italian agriculture

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## INTRODUCTION

In recent years, economic risk management tools in agriculture have been the subject of a renewed interest and profound evolution, not only for the their increasing diffusion in national policies in support to agriculture but also in relation to the important role that they could have in adapting agriculture to climate change. This is because all scenarios currently taking shape show an increase of volatility in climate conditions and extreme events. In addition, agriculture is indeed the most exposed and vulnerable sector to such volatility. Mediterranean and Italian agriculture is particularly fragile in relation also to the wide variety of ecosystems, microclimates and environmental conditions, as well as the variety of agricultural production based on the quality and territorial specificity of its products.

The contribution that economic tools for risk management can bring in this context is related in particular to their flexibility and adaptability to farm needs. In order to be effective, these tools need strong integration in a wider framework of policies and actions on climate change adaptation. Moreover, it is crucial that, when designing these tools, consistency with other key agricultural objectives is ensured, most notably food security and environmental sustainability. Starting from an analysis of tools currently in use at international level and taking into consideration the Italian experience in risk management at national level (the National Solidarity Fund), this paper aims at highlighting both the potential and limitations of risk management tools in the context of climate adaptation and possible or necessary policies and future directions.

## IMPORTANCE OF RISK MANAGEMENT FOR AGRICULTURE

According to the generally accepted economic meaning, risk is a component of a company's activity related to the expectations of an economic result that may not be fulfilled owing to unforeseen events in the planning–production–sale process. In business management, planning seeks to consider all factors that may influence the expected result. However, there are some external factors with unpredictable behaviour that generate uncertainty and potential risk. Generally speaking, the above concepts concern all business activities. However, the agricultural sector presents important peculiarities, as production is strictly correlated to environmental and climate factors that, by their very nature, are hardly subject to management control. In short, agriculture has a higher exposure (to climate events) and higher vulnerability (to the consequences of events).

In particular, the production risk associated with adverse weather conditions[1] (generally speaking, "climatic risk"), understood as the risk that the yields or the quality of production are lower than expected owing to the effect of adverse meteorological or environmental events, has always been considered as a matter of priority and perceived as medium/high risk (in terms of likelihood and damage).

The concept of climatic risk may encompass also the behaviour and diffusion of physiopathologies and parasitic attacks, which appear in the long term to be abnormal as a result of exceptional events.

Agriculture in the Mediterranean basin has a higher degree of exposure and vulnerability to climatic risk compared to other areas for the following reasons:

- It is based on the quality of production rather than on quantity, that is, on production with high added value and with significant economic relevance also in terms of exports. Therefore, equal damages in quantitative terms, correspond to higher economic loss;
- Environmental and climatic conditions of countries of the Mediterranean, most notably Italy, are extremely heterogeneous. This factor renders production more diverse and rich but also entails higher risks for the territorial specificity of production.

Given these considerations, risk management in farms has always represented an important element and, in certain cases, a decisive factor for the farms' very existence.

In this already complex contest for risk management, climate change (CC) raises fundamental questions regarding the future of agricultural production. Compared with baseline scenarios, in fact, climate change increases the level of uncertainty and variability of the environmental conditions under which agriculture operates and thus heavily influences cultivation cycles, agricultural practices and farm management.

Recent and ongoing studies[2] highlight the possible effects of CC on the agriculture of the Mediterranean, most notably Italian, taking into consideration the main climatic variables in different zones of the Member State and, in certain cases, simulating the effects of such changes on specific aspects such as yields, water availability and phytosanitary conditions.

These studies broadly converge in predicting an increase of approximately 1.5–2 °C by 2050 and of 3 °C by 2050, in particular in southern Italy, accompanied by a decrease in annual precipitation and an increase in the frequency of alluvial rain. Such a scenario entails, *inter alia*, a worsening of the desertification process in the most southern regions of the peninsula – not only coastal areas – accompanied by a higher risk of floods.

The supposed repercussions on the biotic component concern in particular the phenological development of agricultural cultivations: not only is a concentration and

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[1] The definition of adverse weather conditions is not clearly defined at international level. According to the European Commission's community guidelines for state aid in the agriculture and forestry sector 2007 to 2013, national disasters include earthquakes, avalanches, landslides and floods. The Commission does not acknowledge the insurgence of plant and animal diseases or exceptional events unless the latter are particularly calamitous (in terms of diffusion) for which the Member State justifies the exceptional nature of such event.

[2] Projects financed by CLIMAGRI, Agroscenari Programme, AdaptAlp.

shift of floristic areas towards cooler and more internal zones being reported, but also, and more importantly, a displacement of all phenological phases, which varies according to the specific cultivation (more pronounced in long-term cultivations, less pronounced in short-term ones)

Concerning productivity, the common understanding – yet to be verified in more specific situations – is that the increase in temperatures and the decrease of precipitations may cause a reduction in production owing to the impacts on irrigation (less water available), cultivation systems (modification of cultivation cycles, hazardousness of pathogens, modification of the entomological_component)_and on animal production. For instance, scenarios on phytosanitary conditions reveal that higher temperatures may favour the development of pathogens also due to the cultivations increased thermal and water stress, thus subject to higher vulnerability, and to the arrival of new pathogens typical of subtropical areas .

Moreover, the impact of the increase of temperatures on animal health and well-being is also being debated: notably, the effect of high temperatures on the nutrition of the breeding stock (reduced appetite and reduced productive and reproductive capabilities as a result of increased stress)

In short, even if agriculture has always adapted naturally to the environmental conditions in which reproduction occurs, the ongoing climatic changes put forward specific problems, such as:

- the speed of the changes in relation to the ability of agri-ecosystems to self-adapt;
- the increasing frequency and the higher magnitude of extreme meteorological events such as drought and floods;
- the uncertainty of climate change scenarios;
- the global production of food: while climate changes may create new production opportunities, they may generate more important preoccupations regarding the ability of agricultural systems to ensure food security for an increasing world population.

The above considerations complicate the context in which business choices take place. The latter become increasingly more uncertain regarding the type and quantity of production and regarding the execution of practices, i.e. seeding, irrigation, phytosanitary intervention and harvesting (when, how, how much). In other words, farmers are today faced with the choice, on the one hand, to continue operating as usual (entailing a higher risk), or investing in a more complete risk coverage, adapting the farm and its management.

Therefore, beyond CC mitigation policies, there is no doubt that considerations and solutions need to be sought in order to adapt agricultural practices to the unfolding climate and environmental scenarios.

## CLIMATE CHANGE ADAPTATION STRATEGIES AND RISK MANAGEMENT

It follows that, inside climate change adaptation strategies, risk management at local and farm levels represents one of the most important elements and key challenges. There are different typologies of actions available, most notably:

- Structural: actions for the improvement of business infrastructure and of the territory in order to reduce the exposure and vulnerability to the effects of CC.

- Management level: improvement of farm and territorial management (business planning, innovation and modernization of management, diversification of activities and production), decision-making support and early warning for drought, floods, landslides and pathogenic attacks.
- Economic: financial and economic tools to cover risk such as insurance, compensation funds, mutual funds, investment funds, etc.

Concerning in particular the latter category, traditional associated tools are considered useful, compared, for instance, with structural or infrastructural investments, for their characteristics of flexibility and adaptability at the stage of definition as well as application (contracts with subject and objectives that are modifiable in time and space). In the context of CC, such characteristics are even more important (and indeed useful) given the uncertainty regarding the effects and impacts on production. This is because economic tools are adaptable in terms of objectives and substance as different scenarios may unfold.

The analysis of the international context demonstrates that the diffusion of risk management in agriculture through these economic tools, primarily insurances, is based on the possibility of benefiting from supportive public policies (Pontrandolfi and Nizza, 2011). In most cases, public support is in fact targeted to the specific needs of each context: adverse climatic events in the EU and North America, and more recently also in Australia, as well as the objectives of agriculture and development in South America, are all cases in point (the most frequent being agricultural insurance).

In this historical context, the main challenge is how to adapt risk management tools as currently being carried out in various countries in order to make them tools for CC adaptation, building on two fundamental considerations.

The transformation of the climatic asset is going to modify (is modifying) the behaviour of the main variables that impact risk distribution both in terms of pattern and of measurement, mainly that of production.

Tendentially, an increase in general levels of risk is to be expected, as well as an intensification of uncertainties and question marks regarding the behavior of the main reference parameters (first and foremost temperature, precipitation and yield).

In summary, if tools and policies for risk management are to be devised that are functional also for adaptation objectives, it will be necessary to review the phases of the process, taking into account the change scenarios as elements for both the risk identification (taking into account also emerging risks) and assessment phases (re-assessment of risks given the changing scenarios).

Given the above considerations, the choice of strategies and objectives should also undergo review and adjustment where needed, always keeping in mind the goal of maximizing the effectiveness of the interventions.

## EVALUATION OF ECONOMIC RISK MANAGEMENT TOOLS IN AGRICULTURE IN ITALY

Italy is among the countries with a strong tradition of risk management through economic and financial tools. This is mainly because of its particular geographic, morphologic, climatic and production characteristics, which determine strong heterogeneity, and thus complexity, of variables as well as higher exposure and vulnerability to risk associated to meteorological and climatic conditions. Since the 1970s, the insurance market had offered single-risk hail insurance policies with the partial coverage of the "National Solidarity Fund for Natural Calamities in Agriculture" established and dedicated to the financial compensation of farmers hit by natural calamities. The fund was subjected to an historical turn with the 2004 reform (legislative decree 102/04), which changed its principles and economic tools. The underlying objective is to promote, via the activation of public funds, prevention actions to address damage, in areas hit by natural calamities or extreme events, to agriculture and zootechnical production, farms and production plants. The types of intervention foreseen are as follows:

a. Measures addressed at providing incentives for the stipulation of insurance contracts: aid for payments of insurance premiums consists of a public contribution up to 80 percent of premiums for contracts with a damage threshold of above 30 percent. The signing of the insurance policies is voluntary and can occur in individual or collective form through agricultural consortia or cooperatives.
b. Compensative interventions for damage to production, infrastructure and production plants: aimed at helping the economic recovery of farms that have suffered more than 30 percent of damage in their gross saleable production.

This approach responds to two different risk management strategies (Pontrandolfi and Nizza, 2011):

- Transfer of risk to third parties, traditionally associated with insurances and generally used for risk management with medium probability of the event happening and with a medium degree of damage.
- Acceptance of risk generally associated with low probability events with a high degree of damage for which the onus appears to be on the farmer to accept to run the risk.

It is important to highlight that the principle of exclusion is foreseen for both types of tools, which is not always applied in other countries: it is not possible to give compensation contributions for insurable damages (included in the annual agricultural insurance plan, approved by ministerial decree of the Ministry of Agriculture)

The 2004 reform and its evolution in 2005–2009 highlight the national policy choice to give more weight to insurance interventions, which today cover around 80 percent of the available funds, compared with public interventions for damage compensation.

Furthermore, in recent years, the demand for and offer of insurances has widened and diversified: the introduction of new insurance types (pluri-risk and multiple risk), in addition to traditional ones (single-risk of hail), has certainly contributed to the diffusion of insurances in areas where they were traditionally lacking. In recent years, there has been a constant increase of pluri-risk policies, which today cover approximately 46 percent of the agriculture insurance market (Razeto, 2011). Pluri-risk insurances linked to unfavourable meteorological conditions (drought, hail, floods) have had a significant diffusion.

At legislative level, a number of already existing opportunities arise from combining EU and Italian law, even if some of them are not considered implementable or of interest for Italy (Table 1). As seen from the table, contributions for insurance premiums can also derive from the Common Market Organisation (CMO) for Wine and Fruit & Vegetables, even if

**Table 1: Allowed tools and risk typologies covered by EU and Italian law**

| Type of risk | Allowed risk management tools | | |
|---|---|---|---|
| | National framework | European Framework | |
| | National Solidarity Fund | Reg. 73/09 | CMO |
| Climatic adverse events | • insurance<br>• compensation funds | • insurance | • insurance |
| Plant diseases and pest infestations | • insurance | • insurance<br>• mutual funds | • insurance |
| Epizootics | • insurance | • mutual funds<br>• insurance | |
| Environmental | | • mutual funds | |
| Market | | | • common investment funds in CMO in fruits;<br>• mutual funds in CMO for wine |

to date only the premiums for the Wine CMO have been utilized. Since 2010, for the first time in the history of the Common Agriculture Policy (CAP), some contributions for risk management tools come directly from the CAP as amended by Regulation 73/2009/EC ("Heath Check" regulation). Specifically, Italy has implemented Article 68 (d) relating to contributions for insurance policies, regarding it as an important opportunity for risk management in the country. Italy is now one of the most active Member States in pointing out the importance of risk management in agriculture in EU policies.

Currently in Italy public contributions for insurances and compensation funds are available. An issue discussed is obviously that of the ability of the system and of insurance policies available in the market to satisfy the exact needs of the agricultural sector with regard to the occurrence and damage caused by adverse meteorological events. The most debated topics are the following:

- At legislative level, the lack of legislative tools that are complementary or supplementary to insurances and compensation funds and that are able to manage other levels and types of risk currently not covered (market, disease, price risks).
- The insurance base is still considered to be excessively low (approximately 18 percent of national production) despite significant public contributions.[3]
- The disparity in geographical distribution with a predominance of premiums in northern Italy (70–80 percent) and enterprises and insurance companies of central and southern Italy that are reluctant to use insurances.

It is worth noticing that, among the needs for innovation that have emerged in recent years, the introduction and diffusion of new tools enabling wider choice and freedom for action to farmers in difficulty, have emerged in particular, given the increase in the frequency of adverse events linked to CC. Mutual funds have spurred a certain degree of interest. Experience with the latter, albeit contingent and intermittent, has demonstrated to be almost always positive. In general terms, the existence of mutual funds that do not benefit from public contributions may imply that the agricultural sector has enough

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[3] Ministero delle Politiche Agricole Alimentari e Forestale (Ministry of Agriculture, Food and Forestry), 2010.

confidence in such a tool. Funds are not seen in contrast with insurances but rather as important and potential complementary tools that are able to cover types and especially levels of risk that are non-insurable: According to an INEA analysis on mutual funds, it has emerged that the stronger competition ensured by the very existence of a fund is generally considered to have a positive effect on insurance policies (they tend to decrease) and their typologies. Essentially, the most evident positive effect is the placing on the market of different risk management tools. Finally, a consideration emerging from the agriculture sector on the conditions of risk: in the areas where insurance premiums paid are much higher than compensation received, the investment in a mutual fund may be considered more effective and useful.

## OPPORTUNITIES EMERGING FROM CAP POST-2013 REFORM

Following the European Commission's communication adopted in November 2011 on future directions for CAP post-2013, a proposal for a Regulation on rural development has been put forward and is currently being negotiated. The proposal, for the first time, introduces in the European Union a comprehensive policy framework of measures and tools for risk management in agriculture. The proposal acknowledges that the agricultural sector is more vulnerable than other sectors to suffer damage to its production potential as a result of natural disasters. Therefore, support to farmers for the recovery of the agricultural assets damaged by natural disasters as well as support for risk management is required. Most notably, the proposal introduces a specific measure for risk management, providing support for:

- crop, animal and plant insurance premiums against financial losses caused by adverse climatic events or by animal/plant diseases or parasitic infections (art. 51);
- mutual funds;[4]
- to pay financial compensation to farmers for losses suffered as a result of the outbreak of animal or plant diseases or environmental incidents (art. 52); contributions may include: the administrative costs of setting up the mutual fund, spread over a maximum of three years in a degressive manner; the amounts paid by the mutual fund as financial compensation to farmers; interest on commercial loans taken out by the mutual fund for the purpose of paying the financial compensation. No contribution of public funds is accepted to the initial capital of the fund (paid by farmers);
- an income stabilization tool, in the form of financial contributions to mutual funds to compensate farmers that have suffered a loss of over 30 percent of their income[5] (art. 53). Payments by the mutual fund to farmers shall compensate for not more than 70 percent of the income lost.

The income stabilization objective in the CAP reform deserves particular attention. Income as a variable is not a component of risk. Income is the final result, while the risk factors are the variables influencing the result.

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[4] By "mutual funds" we mean a regime recognized by the Member State, in line with its legal system (Member States define rules for the establishment and management of funds), which allows member farmers to cover themselves and to benefit from compensative payments in the case of economic losses.

[5] Income reductions must be in excess of 30 percent of the average income of the previous three years or of a three-year average based on the previous five years excluding the highest and lowest years in terms of income. Income is referred to as the sum of revenues that the farmer receives from the market, including any form of public support.

In any case, in the emerging global context, the choice of income stabilization tools represents an emerging and much debated issue since the recent market crises as well as price volatility have emphasized the need to find new ways for income stabilization in agriculture to complement traditional income support measures (present in all Member States via different support policies and tools). On this subject, an intense debate at political and technical level has emerged, including at European level, in the perspective of the future CAP. Some countries have initiated studies and evaluations on the subject (France, Spain, Italy) in order to look at the most problematic aspects, that is, the definition and the calculation of income (links to fiscal systems and historical data analysis) as well as the integration with other tools in order to avoid overcompensation.

The major opportunities arising from a new system would certainly reside in the potential synergies between risk management tools and other rural development measures of a more structural and management nature. The latter can contribute to a reduction of risk exposure and of the farms' vulnerability, first and foremost agro-climatic-environmental measures, production diversification, irrigation infrastructures, technological and management innovations and formation-information- consultancy.

Some concerns about the new system are instead given by the modalities and timing of the rules foreseen for rural development (multi-annual contracts, complex administrative procedures), which might not be in line with the traditional needs of risk management, which necessitates immediate actions for the farm to recover following the damages suffered (it is crucial that contracts be annual and reimbursements are immediately effective).

## CONCLUSIONS

Based on the above, several observations arise on the opportunities offered by economic risk management tools with regard to the objective of adapting agriculture to climate change. There is no doubt that this type of tool may be useful to farms in order to address the increase of climatic risk, in particular considering the uncertainty and complexity of factors involved. In the presence of unforeseeable and extreme events, both in terms of occurrence and magnitude, risk coverage can represent a means for the very survival of the affected farms.

Given this premise, it is however important to highlight that risk coverage through economic tools cannot itself represent the answer to CC, as its intervention limitations as well as its effectiveness largely depend on the conditions in which risk coverage operates, that is, at business and territorial level, where actions are taken to reduce the risk factors within acceptable limits. In other words, economic tools operate within the limits of the risk curve (likelihood and impact of events). If the latter are modified as a result of CC, without rebalancing interventions of another nature, the economic tools may result as ineffective (i.e. insufficient financial coverage of damages or lack of incentives to activate insurances)

By means of example, if flood phenomena increase and the area is not safeguarded from hydrological risks, an economic risk management tool would not suffice to cover the damages caused by an extreme event. Similarly, the tools would lose effectiveness and ability to intervene (claims for damages) if the business does not undergo structural (i.e.

anti-hail nets, improvement of irrigation supply, maintenance of ditches, strengthening and adjustment of infrastructure, etc.) and management-level (risk planning, farm innovation and modernization, diversification, farm advisory system and early warning system) improvements to reduce the impact of CC.

A further point worth underlining concerns the environmental and economic sustainability of economic tools and their consistency with the strategic objective of food security. With regard to environmental sustainability, the main concern is the occurrence of "maladaptation" phenomena, that is, a worsening of the farms' levels of attention, maintenance and innovation – and thus of land, water and soil management – given the presence of an economic tool covering possible damages. The same concern may arise in relation to the food security objective, as these tools safeguard the farmers' incomes. The latter are important for the livelihood of rural communities; however, they do not guarantee production levels, which, generally speaking, are the most affected by the impacts of CC. While it is obviously difficult to estimate the impacts of a wide diffusion of risk management tools on production levels, it represents nonetheless an element worthy of consideration when designing support policies.

These considerations are even more relevant when operating in a national or international policy context: when choosing to allocate public funds to risk management, the ineffectiveness of these tools would imply inefficiency of public spending.

It is thus of crucial importance that risk management tools are placed within a more general integrated risk management strategy for the adaptation of agriculture to CC, which clearly defines complementary actions and structural, management and economic synergies as well as ensuring consistency with other strategic objectives.

At the same time, to exploit the potential of these tools in order to sustain adaptation policies, an update and review of existing tools is needed. First, as mentioned above, a review of risk analysis, including, where possible, the emerging risks in relation to CC as well as rethinking priorities as a result of new climatic conditions, would be necessary. In this context, it is also important to highlight the need for improving the planning process of risk at both business and policy level defining risks, priorities and objectives, and only at a later stage choosing the most appropriate tools for specific conditions. Currently, in fact, the opposite approach seems to prevail in many countries. In other words, there is a tendency to adapt, in some occasions to "force", the existing tools available on the market to manage risks. This approach necessitates higher public funds in order to provide incentives for their use as otherwise these tools would not be available on the market. An example are insurances, which are indeed a very widespread and useful tool, but nevertheless are encouraged also for levels and typologies of risks (i.e. phytosanitary) that are not insurable on the basis of the insurance system's evaluation criteria. Therefore, it also appears necessary to widen the choice of economic tools currently available to farms, which should be able to choose among several options in consideration of their specific needs, thus ultimately improving the efficiency of public expenditure. The analysis of the international context underlines nonetheless that risk management in agriculture cannot, at present, be set apart from public support policies. Therefore, efforts to increase the diffusion of these tools in agriculture need to be accompanied by investments.

Finally, one last consideration arises from the uncertainty of climatic scenarios. In order to support agriculture in these sensitive historical times, while encouraging *ex-ante* tools that cover risks preventively, it appears necessary to ensure the existence of solidarity funds of a compensatory nature (*ex-post*). This is because the difficulty in appreciating the distribution and the intensity of extreme events renders agriculture more vulnerable if only *ex-ante* tools are utilized.

In conclusion, risk management through tools of an economic nature should represent just one component of a wider adaption strategy. Only a multilevel (at farm and territorial levels, with management and structural measures), integrated and consistent (which takes into account various global strategic objectives such as sustainability and food security) approach is able to ensure theeffectiveness of the policies used in the long term.

In summary, the conditions for effectiveness are:

- integrated planning and programming of actions;
- innovative actions : new solutions to new problems, favouring prevention;
- sustainability of actions.

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# The resiliency of the Canadian crop insurance system under climate change: testing quantitative methods

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Resilience is a key attribute identified for systems that can respond to climate change and this includes programmes that help farmers manage risk. Farmers deal with weather variability and extreme events as part of their day- to-day operations. In Canada, they utilize a number of risk management tools provided by the Government with AgriInsurance, Canada's crop insurance programme, being a cornerstone of the suite of business risk managements programmes that are available to farmers. A key policy question is whether crop insurance can continue to provide a robust response when the effects of climate change alter the prevailing weather patterns. This analysis employs a number of models to test methodologies to determine if we have the capacity to undertake this type of policy analysis and to provide at least some preliminary findings.

Using an integrated assessment framework, regionally downscaled climate data from two Global Circulation Models (GCM) – the Canadian GCM and the Hadley GCM – were used to generate daily data for the period 2040 to 2069. The EPIC (Environmental Policy Integrated Climate) crop growth model was calibrated to better reflect growing conditions in the Prairie region and used to generate a new set of yields for the principal Prairie crops for each of the 22 crop districts based on the GCM-derived weather data. To establish a baseline, EPIC was also run on weather data for 1971 to 2000. From this annual yield data, both means and variance-covariances were generated for the baseline and the scenarios with climate change, with and without a $CO_2$ fertilization effect. These data were incorporated into a regional, partial equilibrium, optimization model (CRAM), developed by Agriculture and Agri-Food Canada (AAFC) to undertake policy analysis. A risk version of the model is employed for this analysis to reflect the fact that farmers would respond to relative change in expected yields owing to climate change, as well as to the expected change in the variance of those yields. To ascertain how resilient crop insurance would be with climate change, a Monte Carlo simulation with CRAM was run with draws from the generated yield data, allowing farmers to continue to employ crop insurance to manage yield risk related to weather.

Based on 10 000 simulations for each experiment, Canada's crop insurance programme proved to be resilient in that the average annual deficit for the programme (extent to which payouts exceeded premiums paid by both producers and government) remained similar when the results for the historic period were compared to the future climate change scenarios. In fact the deficit declined slightly with climate change, in part owing to lower average yields and therefore slightly lower exposure. The modeling system employed here can help to analyse real policy questions, but further developmental work is required to ensure all the complexities related to this type of analysis are dealt with, for example that weather patterns can exhibit longer run dry and wet cycles that should be reflected in the experimental design. A key advantage of the approach here is a risk framework with changes in means and variances effecting production decisions for a cropping rotation at the regional level.

# Exploring adaptation of agriculture to climate change: policy choices and resiliency

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## INTRODUCTION

Climate change is a major source of uncertainty for today's vulnerable societies. Prioritizing adaptation policy to these uncertain conditions is a major challenge This uncertainty is especially relevant for agriculture and food security, given that both sectors link to ecosystems, water, cities and culture. Climate change comes in conjunction with high development pressure, increasing populations, water management that is already facing conflicts and agricultural systems that are often no longer conducive to local conditions.

Understanding the impacts of climate change on agriculture as a whole requires a multidimensional analysis at the global level that requires information on a measure of the potential impacts and a measure of the potential limits (social and physical) to adaptation.

## METHODS

The innovative aspects of the analysis lie in the multidimensional nature of the assessment and on its use of the latest generation of climate scenarios. Here we undertake such an analysis in two steps. First, we apply the ClimateCrop model (Iglesias *et al.,* 2012), which evaluates crop productivity and water demands as a response to climate adaptation policies (i.e. related to water and land use) and mitigation policies (i.e. related to nitrogen fertilization). Second, we develop an adaptive capacity index to evaluate the resilience of regional agricultural systems.

## RESULTS AND DISCUSSION

The need to respond to the regional risks and opportunities is addressed by evaluating the costs and benefits of a number of technical and policy actions on crop productivity, water demand for agriculture and fertilizer use. The results assist in the understanding of how adaptation planning can help strengthen food production in a changing climate and develop measures to reduce the vulnerability of the sector to climate change. However, adaptation planning is inherently complex since it also requires a measure of resilience. Our results show clear linkages have also been demonstrated between poverty and agricultural capacity.

The likelihood is that climate change impacts will continue to increase as long as adaptation and mitigation strategies are not put in place. Currently, the countries with the most adaptive capacity are also those which enjoy higher levels of socio-economic development; a number of countries highly dependent on agriculture do not enjoy the same levels of adaptive capacity and their vulnerability to climate change is thus intensified. These cases highlight the need for a strategic approach to adaptation.

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# Towards climate-resilient agriculture: the Dutch touch

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The dual relationship between agriculture and climate change is captured in:

1) the impacts of climate change on agriculture via, for example, dry periods, salinization, new diseases and plagues. And critically important for a lowlying coastal country like the Netherlands: flooding!
2) via greenhouse gas emissions agriculture contributes to climate change.

In the Netherlands there are two complementary approaches for agriculture:

- national efforts on climate change targeting the Dutch agrosectors;
- at international level the need to promote food security and climate smart agriculture.

The Dutch approach is based on intensive cooperation between the private sector, scientific institutes and the government: the golden triangle. It is a starting point for the Dutch enterprise policy and agriculture policy. It is also becoming a priority in our development cooperation efforts. A specific feature of our climate change policy is that we encourage linking adaptation and mitigation interventions. An example of this approach is the project "Adaptation to climate change in agriculture in Northern Netherlands".[1] The aim of the project was to develop strategies and action plans for agriculture to adapt to both climate and market changes. The project focused on three questions:

*1. What are the threats and impacts on arable farming in the region?*
This is about governance and the strategic choice whether a sector has strategic and future importance. A basic question is whether large investments in adaptation efforts are justified. The learning issue is to not to hang on to present sectors and production systems but also look at the future importance.

*2. What are the impacts of extreme events and how to identify adaptation measures?*
Here the focus is on impact and adaptation at field and farm levels looking at the influence of extreme events on crop production. Science and farmers work closely together. An "agro climate calendar" was set up as a tool to deal with estimating the climatic impact on crop or animal production. This phase also identified adaptation strategies.

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[1] The Dutch Federation of Agriculture and Horticulture, LTO Noord, together with Wageningen University and research centres.

*3. How to identify regional and farm level adaptation action plans?*

This concerns regional and farm level action plans: identify bottlenecks and challenges, draw up adaptation strategies and action plans and finally ensure the use of proper forms of risk management.

The learning issues are:

- doing things differently (i.e. water management);
- doing different things (i.e. new [robust] production systems).

Food security is important for many developing countries. Besides the importance of markets, a stable food production base, that keeps pace with an increasing population, is crucial for achieving food security. Increasing production also means introducing new, climate-resilient, working methods.

The foci of the Netherlands are:

- facilitate global discussions on agriculture, food security and climate change;
- contribute to concrete actions and excellent preconditions;
- contribute to capacity building via organizing workshops and courses.

Climate change is clearly a global problem and therefore requires a global solution. For that reason, the Netherlands remains committed to contributing to concrete actions and to facilitating international discussions on agriculture, food security and climate change.

# The EU agricultural policy – delivering on adaptation to climate change

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The fight against climate change and its likely impacts is one of the major political priorities at global level and has been retained by the European Commission (EC) in its "Europe 2020 strategy".

EC is preparing a European Adaptation Strategy (to be launched in March 2013). The objectives are to: improve and widen the knowledge base where gaps have been identified and enhance dissemination of adaptation-related information; support and facilitate exchange between Member States (MS), regions, cities and all other relevant stakeholders; develop initiatives for a more consistent and comprehensive integration of climate change adaptation into EU policies, including the Common Agricultural Policy (CAP); and make further the case for public and private action on adaptation.

The current CAP contributes to adaptation by providing a basic level of income security to farmers, by shifting to decoupled support, which enables adaptation to market and agronomic conditions, as well as to climatic conditions, and by providing a basic framework for sustainable management of the natural environment (cross cross-compliance).

In addition, the support within the rural development policy provides possibilities for targeted support to a wide array of adaptation measures involving building adaptive capacity and implementing actions. However, planned adaptation measures are currently at a relatively early stage of development in the ongoing rural development programmes (RDP) for the period 2007–13. Large uncertainties of the climate effects remain for the time horizon of 2020–2030, particularly at detailed spatial scale, which makes planning difficult in many regions. The current focus is on actions that provide adaptive capacity (training, demonstration projects, information), rather than operations that either seek to reduce the risk or reduce the exposure. Most of the expected impacts on agriculture will come through water. All present discussions on adaptation in the EU involve water management as water is already a scarce resource in some catchments and risk of water stress is a key driver for change.

The CAP for the period 2014–2020 is currently being negotiated in the Council of the EU (which gathers MS) and the European Parliament. Today, the CAP needs to respond to some very new challenges, some of which are external ones. These are economic, environmental and social.

- The economic and financial crisis has exacerbated several economic challenges, relating to food security, income viability and severe price fluctuations, and squeezed margins owing to higher prices for inputs such as feed and energy. The variability of crop yields has indeed increased over the last decades as a consequence of extreme climatic events. European farmers will need to define their strategies for production, farm management and investment in the face of increasing uncertainty.
- The environmental challenges traditionally faced by agriculture are being exacerbated by climate change. Now, more than ever, farmers have to contribute to climate change mitigation; they have to face climatic changes that are also impacting the natural environment on which agriculture and livestock takes place.
- And thirdly, there is the territorial challenge, which is an important objective of the EU to ensure that rural areas remain vital, through making agriculture more diverse and reversing the demographic trends. The uneven effects of climate change are expected to amplify regional differences and exacerbate economic disparities between European rural areas.

The new CAP aims to achieve three basic objectives of the European Union: to make our agriculture more competitive; to make it more environmentally sustainable; and keep vital agricultural activities and rural areas across EU territory. On the environment front, the aim of the next CAP will be to manage natural resources more sustainably, to strengthen mitigation of GHG emissions and enhance farmers' resilience to threats posed by climate change and variability. This is therefore the first time that the concept of resilience explicitly enters into the CAP objectives.

The slide presentation gave an overview of changes proposed in the CAP by focusing on how adaptation would be further promoted. The EU intends to further pursue and support adaptation in the agricultural sector with four types of instruments:

- Measures for sustainable management of natural resources (new “green” payment as part of income support, enhanced cross-compliance for climate change; enhanced environmental and climatic focus for support within rural areas). One of the key changes proposed for rural development policy is to structure forthcoming RDP around “priorities” (and associated “focus areas”). Six priorities have been set, of which two relate to environment and climate, such as promoting resource efficiency, with a focus in particular on increasing efficiency in water use by agriculture, and low carbon and climate-resilient agriculture.
- Financial support (continuation of agri-environment-climate measures, enhanced support for risk management instruments, such as insurances, mutual funds).
- Research and innovation (proposed support for research and innovation (from Euros 1.9 to 4.5 billion) and a new European Innovation Partnership on “Agricultural productivity and sustainability” to help reconcile agronomy and ecology.
- Knowledge transfer and information actions (improved Farm Advisory instrument covering climate-related issues).

Some final considerations were made to point out that:

- There is global warming, but impacts are local – the adaptive potential of farmers and rural areas is very different across the EU and a “one size fits all approach” is not feasible.
- Adaptation planning is challenging (e.g. projection uncertainties, complex interactions, climate/agronomic factors, long planning horizon) but can also bring opportunities to build more resilient agricultural systems in climatic and economic terms.
- Focus needs to shift from uncertainty as a barrier to step up action. Building resilience encompasses a broad range of actions, not necessary climate-specific, but which can help to cope with climate variability and change. This can obviously help to shift focus from uncertainties as a barrier to other objectives such as management of farms for overall socio-economic-ecological resilience.
- It is very likely that, in the next years, autonomous (bottom-up) adaptation driven by farmers as a continuation of traditional risk management will prevail over planned (top-down) adaptation responses. This idea has also been put forward by some speakers who pointed out that adaptation to long-term climatic changes starts with managing current climatic variability and environmental problems.

# The Swiss climate strategy for agriculture at a glance

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Reducing greenhouse gas emissions and adapting to climate change are among the most important environmental, social and economic challenges today, as they will be in the future. This applies to all sectors of our society on a global level, a national level and even a regional level. In this respect, agriculture and food production have a major role to play. They have the potential to make a contribution towards mitigating climate change, namely by reducing greenhouse gas emissions, by increasing and preserving soil carbon pools and by producing renewable energy. In order to continue to be able to ensure food supplies and provide social, economic and ecosystem services, agriculture and food production must also adapt to climate change. Steps and measures must be taken in good time if full use is to be made of the opportunities that arise.

The Swiss climate strategy for agriculture should be a guiding light for agriculture and food production in Switzerland in their efforts to reduce greenhouse gas emissions and adapt to changing conditions. The strategy sets out common guidelines and long-term targets and identifies priorities and possible areas where action can be taken.

## THE DUAL ROLE OF AGRICULTURE

Agriculture and food production contribute to climate change and are at the same time affected by it. On the one hand, they have a direct influence on trends in concentrations of greenhouse gases in the atmosphere through the fact that they release greenhouse gases and store carbon. On the other hand, climate change influences the conditions under which agriculture operates.

According to the national greenhouse gas inventory, the agriculture sector emitted 5.6 million tonnes of $CO_2$ equivalent in 2009, which is a good 10 percent of total emissions in Switzerland. Unlike most sectors of the economy, the proportion of fossil $CO_2$ emissions from agriculture is low. In contrast, with regard to methane and nitrous oxide, agriculture is the main emitter, being responsible for 80 percent and 75 percent of total emissions, respectively. Between 1990 and 2009, emissions from the agriculture sector decreased by a good 8 percent.

At a general level, climate change in Switzerland is resulting in a shift of suitable areas for agricultural production, and involves both positive aspects (e.g. a longer vegetation period) and negative aspects (e.g. increasing problems regarding pests owing to the milder winters). The increase in extreme weather events is a major problem since they reduce the reliability of harvests. For example, the combination of high temperatures and low rainfall during the heatwave of 2003 led to a marked drop in crop yields. Even in a small country such as Switzerland the effects of climate change are not homogenously distributed: there are regional differences and it can depend on the individual farm's starting point if the changes are positive or negative.

## TARGET

By anticipating its adaptation to climate change it should be possible for the Swiss agriculture sector to improve production and public services over the long term. As far as the reduction of greenhouse gases is concerned, the target comprises two parts: first, emissions by the agriculture sector are to be reduced by at least one-third by 2050, and second, with regard to food (production and consumption) an overall reduction of two-thirds should be achieved. These are ambitious targets but ones that are realistic over the long term. They include the aspect of food security and are based on the commitment of the international community to prevent an increase in global temperatures of more than 2 °C. In this way, agriculture and food production will make a contribution to ensuring a sustainable society.

## PRIORITIES IN ADAPTATION AND MITIGATION

With regard to adaptation to climate change, the resilience of Swiss agriculture is to be improved as a preventive measure in order to cushion the negative effects of extreme weather events. As far as reducing emissions is concerned, the aim is to consistently take advantage of the potential for improving efficiency and to reduce the use of non-renewable energy and products.

There are numerous synergies between adaptation and mitigation that should be used to the full. Consideration of the suitability of a location and optimizing the spatial organization of farming activities can lead to greater efficiency in the use of resources as well as helping to maintain today's level of production. Increased soil protection can be advantageous through the link between humus content, soil structure and water infiltration and holding capacity with regard to climate protection (carbon storage) as well as adaptation to climate change (reducing erosion, improving water balance). High productivity along with good health among livestock are key aspects with regard to emissions per production unit in cattle farming.

There are many areas where action can be taken, ranging from livestock and plant breeding to integrated crop protection, water-saving irrigation systems, foresight and early warning systems, and low-emission livestock housing. The challenge is to choose those that allow for mitigation and adaptation to climate change with optimum cost efficiency. As long as there is a lack of data in this respect or as long as data cannot be drawn up for the more distant future, priority must be given to those options that involve multipurpose or low-cost measures that are practical and effective.

## STAKEHOLDERS

Depending on their location and the conditions under which they operate, Swiss farms are affected by climate change in different ways. The possibility of reducing greenhouse gas emissions also varies from one farm to another. In view of the slow rate of change and the complex interrelationships, it is extremely difficult for farmers to take the right decisions early on.

Farmers need support from other bodies: research and extension services, private players throughout the food production chain or directly related to agriculture (breeders, manufacturers of agricultural machinery, the chemical industry, insurance companies, food processing firms, wholesale distributors, etc.), as well as politics and administration. Finally, in their choice of the food they buy, consumers have a decisive influence on production.

## AREAS TO CONSOLIDATE

In order for the Swiss climate strategy for agriculture to be successful it is necessary to draw up a solid scientific basis, to create an appropriate legal framework and to empower the stakeholders concerned.

**Scientific basis:** Lack of knowledge will be remedied and climate-friendly measures and ways of adapting will be drawn up. Their effect will be estimated individually and in combination and the set of priority measures required to achieve the targets will subsequently be decided. A comprehensive inventory of emissions and observations of the relevant effects of climate change are essential prerequisites. Useful tools in research and extension for climate change adaptation are: development of indicators for adaptation (impact and response), predictions (water supply and demand, pests), modelling the present and future climate suitability of different crops on maps, etc.

**Legal framework:** Future agricultural policy should include creating conditions that encourage efficient adaptation and effective reductions. Measures that involve a longer preliminary process should be introduced in good time and, in particular, in the case of decisions with long-term effects that involve high investment, it should be possible to choose climate-friendly and reliable alternatives. Contributions from other areas are also required: for example, high emission reductions on a global scale, mainly in the transport and housing sector, as well as an improved protection for agricultural land are essential if the targets are to be achieved. Further work in relation to climate change adaption includes: evaluation of the existing policy (are there any regulations that hinder adaptation and which specifications could foster adaptation?) and development of new policy instruments (for example, payments for a climate-smart production system). Cross-sectoral issues such as water-use regulation (integrated water basin management) and monitoring of pests and diseases have to be treated within the framework of national adaptation strategy and action plans.

**Participatory process:** Creating awareness on the issue and spreading information are also essential, as is the creation of possibilities for networking and exchanging ideas.

**Practice:** This involves the concrete implementation of new approaches: the stakeholders instigate joint projects and develop innovative technology and concepts.

If all stakeholders in the agricultural and food production sectors accept their responsibility it will be possible to achieve the ambitious targets set out in the Swiss climate strategy for agriculture.

# Japanese adaptation policy and the analysis and mapping of impacts under Climate Change for Adaptation and Food Security Project

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In Japan, relatively low temperatures continued up until the 1940s, but then started to rise. After experiencing high temperatures in around the 1960s and rather low temperatures until the mid-1980s, the temperature rapidly rose from the late 1980s. Many of the years that marked record-high temperatures in Japan are concentrated in the 1990s and onwards. The frequent occurrence of high-temperature years in Japan can be construed as a combination of global warming caused by an increase in greenhouse gas emissions represented by carbon dioxide and the natural fluctuation repeated with a cycle of a few years or a few decades.

Recently, damage to agricultural products has been reported, and a change of suitable areas for cultivation is projected. In the case of apples, the entire area of Hokkaido will be suitable, while Kanto and further south will be excluded. In order to adapt to global warming, the following measures are currently taken:

- Awareness of the impact of warming: agricultural research institute publicize reports on the impacts of global warming and incorporation of adaptation measures throughout the nation.
- Technical support system for producing areas: establishment of an examination committee and a support team of specialists, which provides advice and guidance to producing areas where impacts of warming are evaluated as severe through local examination.
- Support for adaptation measures (techniques): support for the private sector to develop vegetable species that are resistant to warming, and support for incorporating fog coolers, etc. that prevent disorders of agricultural products caused by high temperature.

Besides domestic policy, Japan has funded FAO to proceed with the Analysis and Mapping of Impacts under Climate Change for Adaptation and Food Security (AMICAF) project as international cooperation. This project deals with how climatic change can impact on food security. In step 1, the impacts of climate change on agriculture are analysed using FAO’s existing MOSAICC (Modeling System for Agricultural Impact of Climate Change) system. This model utilizes four components; climate scenario down-scaling, hydrological modeling, crop growth simulation and economic modeling. In step 2, food insecurity vulnerability analysis at household level will be conducted, using micro-econometric methods. Here, vulnerable household groups will be identified and categorized under the different climate change scenarios. Factors that contribute to household food insecurity will also be assessed. The location of vulnerable household groups will then be indicated by mapping. In step 3, community-based adaptation in vulnerable communities as well as the most relevant adaptation option will be identified, validated and tested in the field. In step 4, institutional analysis and awareness-rising will be conducted. After this project, global guidelines for implementation in other countries will be developed. Finally, in step 4, the project will conduct awareness-rising aimed at relevant stakeholders. At the same time, the project assesses how and which policy support measures can constitute an appropriate incentive for the adoption of the adaptation options. This will be followed by policy recommendations for the design and implementation of selected adaptation options.

# Australia’s Carbon Farming Initiative

*Eliza Murray, Director, Department of Climate Change and Energy Efficiency, Australia*

Australia’s Carbon Farming Initiative (CFI) allows farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land. These credits can then be sold to people and businesses wishing to offset their emissions. The CFI also helps rural communities and the environment by encouraging sustainable farming and providing a source of funding for landscape restoration projects.

Reducing greenhouse gas emissions from the land is important in Australia since agriculture and forestry currently account for about 23 percent of the nation’s emissions. Without a contribution from these sectors it will be increasingly difficult for Australia to achieve its long-term emissions’ reduction target of at least 80 percent below 2000 levels by 2050.

Carbon credits generated under the CFI represent reductions in greenhouse gases in the atmosphere through:

- increasing the amount of carbon stored in soil or trees, for example by growing a forest or reducing tillage on a farm in a way that increases soil carbon; or
- reducing or avoiding emissions, for example through the capture and destruction of methane emissions from landfill or livestock manure.

Offset projects established under the CFI must use methodologies approved by the Government to calculate the number of credits earned. An independent expert committee, the Domestic Offsets Integrity Committee, assesses methodologies and advises the Government on their approval, ensuring each project leads to real and measurable reductions of emissions.

The CFI legislation also includes measures to minimize fraud and dishonest conduct and ensures that consumers can have confidence that credits are genuine. These include crediting only after emissions’ reductions have occurred, a test to ensure project developers are ‘fit and proper’ persons, issuing and tracking credits in a central national registry, requirements for project information to be published, appropriate enforcement provisions to address non-compliance, and regulation of the issuance, transfer and retirement of credits as financial products.

Practical examples of CFI projects could include:

- The frequency and severity of savannah fires can be reduced by carrying out controlled burning earlier in the dry season, when there is less fuel on the ground. This will lead to reduced greenhouse gas emissions in the savannahs of Australia’s tropical north. Such activity has biodiversity benefits and will provide new employment and economic opportunities for indigenous Australians.

- Manure management could enable farmers to reduce emissions from intensive livestock such as piggeries. The emissions can be captured and flared or used to produce heat and electricity.
- Land managers may increase the amount of carbon stored on their land through vegetation. Revegetation along waterways, for example, can improve water quality and have biodiversity benefits. Integrating trees into agricultural systems can protect soils, prevent erosion and provide biodiversity habitat, as well as protect livestock.

# Agricultural response to a changing climate: the role of economics and policy in the United States of America

*Marca Weinberg*
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A changing climate will create new challenges for farmers and policy-makers. Farmers will face changes in productivity, pest outbreaks and extreme weather events. Farmers are resilient; throughout history they have adjusted to regional differences in climates, soils and agronomic conditions, as well as to changes in demand for crops, new technological developments, and changing policy environments, and they are likely to adapt to new conditions as well. However, adjusting to new climates will not be costless, and may have distributional and policy implications.

Farmers can adapt by diversifying crop and livestock types and varieties, adopting new technologies, using alternative tillage practices, implementing irrigation practices and changing the timing of farm operations, among other choices. In the United States of America, they can also purchase crop insurance to reduce the risks of climate-related income loss, invest in crop shares and futures to reduce the risks of climate-related income loss and diversify sources of household income

Global climate models predict increases over time in average temperature worldwide, with significant impacts on local patterns of temperature and precipitation. The extent to which such changes present a risk to food supplies, farmer livelihoods and rural communities depends in part on the direction, magnitude and rate of such changes, but equally importantly on the ability of the agriculture sector to adapt to changing patterns of yield and productivity, production cost and resource availability. Potential constraints to adaptation may include regional land and water availability, as well as constraints related to farm finances and viability.

A recent report by the US Department of Agriculture's Economic Research Service suggests that, while impacts are highly sensitive to uncertain climate projections, farmers have considerable flexibility to adapt to changes in local weather, resource conditions and

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[1] With contributions from Scott Malcolm and Liz Marshall (Economic Research Service [ERS], USDA), and Tom Worth (Risk Management Agency, USDA). The views expressed are those of the author and do not necessarily reflect those of ERS or USDA.

price signals by adjusting crops, rotations and production practices. Such adaptation, using existing crop production technologies, can partially mitigate the impacts of climate change on national agricultural markets. Adaptive redistribution of production, however, may have significant implications for both regional land use and environmental quality.

Options for government and policy responses include research and development on new crop varieties, improved early warning systems that provide daily weather predictions and seasonal forecasts, water management innovations, financial and technical assistance for adopting conservation practices, extension support, and supporting risk management tools such as crop insurance.

Effective crop insurance policies provide financial stability for growers; financially stable growers are more likely to invest in new growing practices to adapt to climate change. Premium rates can act as a price signal to farmers about risk and the value of mitigation or adaptation. The United States crop insurance programmes adjust premium rates based on historical losses and so can reflect gradual changes in risk. However, adjusting programme parameters to reflect non-linear and sudden changes, such as establishment of new practices for new areas or crops, remains a challenge.

Globally, climactic conditions are increasingly variable, and the intensity of their effects stronger. As climate change brings new uncertainties, risks and changes to already existing risks, one of the most efficient ways for agriculture to adapt is increasing its resilience.

In April 2012, the joint FAO/OECD Workshop on “Building Resilience for Adaptation to Climate Change in the Agriculture Sector” was held to address these issues in different agro-ecological and socio-economic contexts, and to illustrate how building resilience is critical to adapting to climate change. The various sessions of the Workshop questioned the notion of resilience from very different angles, confronting concepts, specific risk management strategies, case studies and national policies, from different perspectives – biophysical, economic, or social and institutional – and at various scales, from farm and household to national and global. This publication is a compilation of the papers presented at the Workshop, and the Workshop Summary.

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