

Climate, agriculture and food security:

A strategy for change



The Consultative Group on International Agricultural Research (CGIAR) is a strategic partnership of countries, international and regional organizations and private foundations supporting the work of 15 international agricultural research centres and currently five Challenge Programs. In collaboration with national agricultural research systems, civil society and the private sector, the CGIAR strives to foster sustainable agricultural growth through high-quality science aimed at benefiting the poor through stronger food security, better human nutrition and health, higher incomes and improved management of natural resources.

The Alliance of the CGIAR Centers is a coalition created by the 15 international centres in 2006 to enhance collective action among the centres and between the centres and their partners.

This report was commissioned by the Alliance of the CGIAR Centers, and developed in collaboration between the Alliance and the Challenge Program on Climate Change, Agriculture and Food Security (CCAFS).

CCAFS is a new 10-year research initiative launched by the CGIAR and the Earth System Science Partnership (ESSP). CCAFS seeks to overcome the threats to agriculture and food security in a changing climate, exploring new ways of helping vulnerable rural communities adjust to global changes in climate.

The report was funded by the Danish International Development Agency (Danida).

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Photo (front cover): Arne Hoel

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December 2009

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Foreword



The spectre of climate change has been with us for a long time. As early as 1896, the Swedish chemist and Nobel Prize winner Svante Arrhenius published a paper discussing the role of carbon dioxide in the regulation of the global temperature and calculated that a doubling of CO₂ in the atmosphere would trigger a rise of about 5–6°C. In more recent years we have moved to a better understanding of what this means for our planet and its people, and we have developed some plausible approaches to tackling the problem. However, we have yet to implement most of them.

Over the past few years the temperature has been rising in many senses. Within 12 months in 2006–2007, the Intergovernmental Panel on Climate Change (IPCC)'s 4th Assessment Report and the Stern Review were published and Al Gore's Oscar-winning "An inconvenient truth" reached cinemas all over the world. The scientific assessments, economic analysis and public outreach have raised public debate and political discussion to great heights, especially in the developed world.

Perversely, however, it will be the poorest in developing countries that will be the hardest hit. The menace of global climate change has brought hundreds of millions of rural people in the developing world to a crossroads. It is clear in which direction they need and want to go – from debilitating risk to heightened resilience in the face of an ominous threat to their well-being. And it is equally clear that urgent steps are needed to help them to move in that direction.

Much of the interest so far in relation to climate change and agriculture has been on mitigation, but the focus is changing towards

adaptation, since we know that some global warming is unavoidable. Agriculture and forestry are central to the debate, since the sectors contribute about one-third of the global warming potential but are also very sensitive to a changing climate. In addition, food security is again high on the political agenda with about 1 billion people going to bed hungry every night.

The Consultative Group on International Agricultural Research (CGIAR), established in 1971, is a strategic partnership of countries, international and regional organizations and private foundations supporting the work of international agricultural research centres and Challenge Programs. In collaboration with national agricultural research systems, civil society and the private sector, the CGIAR strives to foster sustainable agricultural growth through high-quality science aimed at benefiting the poor through stronger food security, better human nutrition and health, higher incomes and improved management of natural resources.

Climate has been central to much of the work of the CGIAR centres, variable and uncertain weather being one of the greatest challenges to small-scale farmers and other resource managers. New technologies and knowledge resulting from this work include hardier crops and better ways to manage trees, livestock, water, soil and fish. Thus, the centres and other Challenge Programs have already contributed insights into the role of agriculture, forestry and fisheries in addressing both mitigation of, and adaptation to, climate change. Climate change adds to the urgency of such work, and reinforces its importance.

The CGIAR Challenge Program on Climate Change, Agriculture and Food Security (CCAFS)

is a new drive to help deal with an escalating problem. Developed by the Alliance of CGIAR Centers and the Earth System Science Partnership (ESSP), it aims to ensure that we can sustainably produce sufficient food, fodder and fibre for a growing global population under a changing climate. CCAFS will bring together the best brains in development research, agricultural research and climate science to help bring lasting solutions to the food security challenges under a changing climate.

To highlight the importance of agriculture, livestock, forestry and fisheries in relation to climate change adaptation and mitigation and to demonstrate the importance of the CGIAR in moving the science agenda forward, the Alliance of the CGIAR Centers commissioned this report. The report is organized around the six themes of the CCAFS science plan to emphasize the importance of this new strategic initiative and to show how this new Challenge Program builds on, and complements, the work already done by the centres and the other Challenge Programs. This report will be an important input to the Agriculture and Rural Development Day and to the Forest Day held in Copenhagen in conjunction with the United Nations climate negotiations in December 2009. With a focus on "The road after Copenhagen: priority strategies and actions for ensuring food security and rural development in the face of climate change", the Agriculture and Rural Development Day will bring together policy makers and negotiators, rural development practitioners, producers, civil society and the agricultural and climate change scientific community to highlight the importance of agriculture in climate change and to identify



Stephen Hall

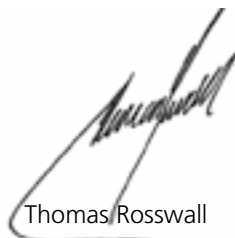
*Chair
Alliance Executive*

the 'no-regret' priorities for agriculture and food security where the world needs to take action. The event will develop a workplan with strategies and actions to fully incorporate agriculture into the post-Copenhagen agenda.

The report was written by Anne Moorhead of Green Ink, based on inputs provided by Contact Points at the CGIAR centres and Challenge Programs. We acknowledge the skills of Anne in writing the report and summarizing the current and planned work in a way that clearly demonstrates the important role of the CGIAR in the follow-up to the COP-15 negotiations in Copenhagen. We are also grateful to the Contact Points for providing inputs to the writing and commenting on drafts.

The report was made possible through generous financial support from Danida, the Danish International Development Agency, and this is gratefully acknowledged.

There is no time to lose in transforming knowledge into action. But the knowledge of today is not enough. Science must advance quickly toward new frontiers, in search of greater understanding and more powerful solutions. We hope that this report will inform and stimulate discussions in Copenhagen during COP-15 and beyond. The CGIAR centres, their partners, and the international science community will continue to provide the solid basis of scientific understanding to assist policy makers as well as the public and private sectors in developing strategies for sustainable development and food security under climate change. Agriculture in its widest sense will be affected by a changing climate, but is also part of the solution.



Thomas Rosswall

*Chair, Steering Committee
Climate Change, Agriculture and Food Security
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Definitions and explanations



Adaptive strategies

Longer term (beyond a single season) strategies that are needed for people to respond to a new set of evolving conditions (biophysical, social and economic) that they have not previously experienced.

Challenge Program

A CGIAR Challenge Program is a time-bound, independently governed programme of high-impact research, that targets the CGIAR goals in relation to complex issues of overwhelming global and/or regional significance, and requires partnerships among a wide range of institutions in order to deliver its products.

Climate

The statistical description in terms of means and variability of key weather parameters for a given area over a period of time – usually at least 30 years.

Climate change

Any change in climate over time, whether due to natural variability or as a result of human activity.

Coping strategies

Strategies that have evolved over time through peoples' long experience in dealing with the known and understood natural variation that they expect in seasons combined with their specific responses to the season as it unfolds.

Earth System Science Partnership (ESSP)

The ESSP was established in 2001 to promote cooperation for the integrated study of the earth

system, the changes that are occurring to the system and the implications of these changes for global sustainability. The ESSP comprises four international global environmental change research programmes: DIVERSITAS, specializing in biodiversity and agrobiodiversity; the International Human Dimensions Programme on Global Environmental Change (IHDP), specializing in institutional, socioeconomic and human security issues related to global environmental change and the policies to address it; the International Geosphere–Biosphere Programme (IGBP), specializing in the physical, chemical and biological processes that define Earth system dynamics; and the World Climate Research Programme (WCRP), specializing in climate science.

Food systems

Food systems encompass activities related to production, processing, distribution, preparation and consumption of food; and the outcomes of these activities that contribute to food security, such as food availability, food access (including affordability, allocation and preferences) and food use (including nutritional value, social value and food safety).

Food security

Food security is the state achieved when food systems operate such that “all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO).

The climate is changing, and agricultural systems must also change if we are to avoid catastrophe

Introduction

Agriculture – on which we all depend for our food – is under threat from climate change. There is no doubt that systems worldwide will have to adapt, but while consumers may barely notice in developed countries, millions of people in developing countries face a very real and direct threat to their food security and livelihoods.

Even without climate change, many agricultural systems in developing countries are nearing crisis point. Feeding a rapidly rising global population is taking a heavy toll on farmlands, rangelands, fisheries and forests. Water is becoming scarce in many regions. Climate change could be the additional stress that pushes systems over the edge.

We know that climate change will mean higher average temperatures, changing rainfall patterns and rising sea levels. There will be more, and more intense, extreme events such as droughts, floods and hurricanes. Although there is a lot of uncertainty about the location and magnitude of these changes, there is no doubt that they pose a major threat to agricultural systems. Developing countries are particularly vulnerable because their economies are closely linked to agriculture, and a large proportion of their populations depend directly on agriculture and natural ecosystems for their livelihoods. Thus, climate change has the potential to act as a 'risk multiplier' in some of the poorest parts of the world, where agricultural and other natural resource-based systems are already failing to keep pace with the demands on them.

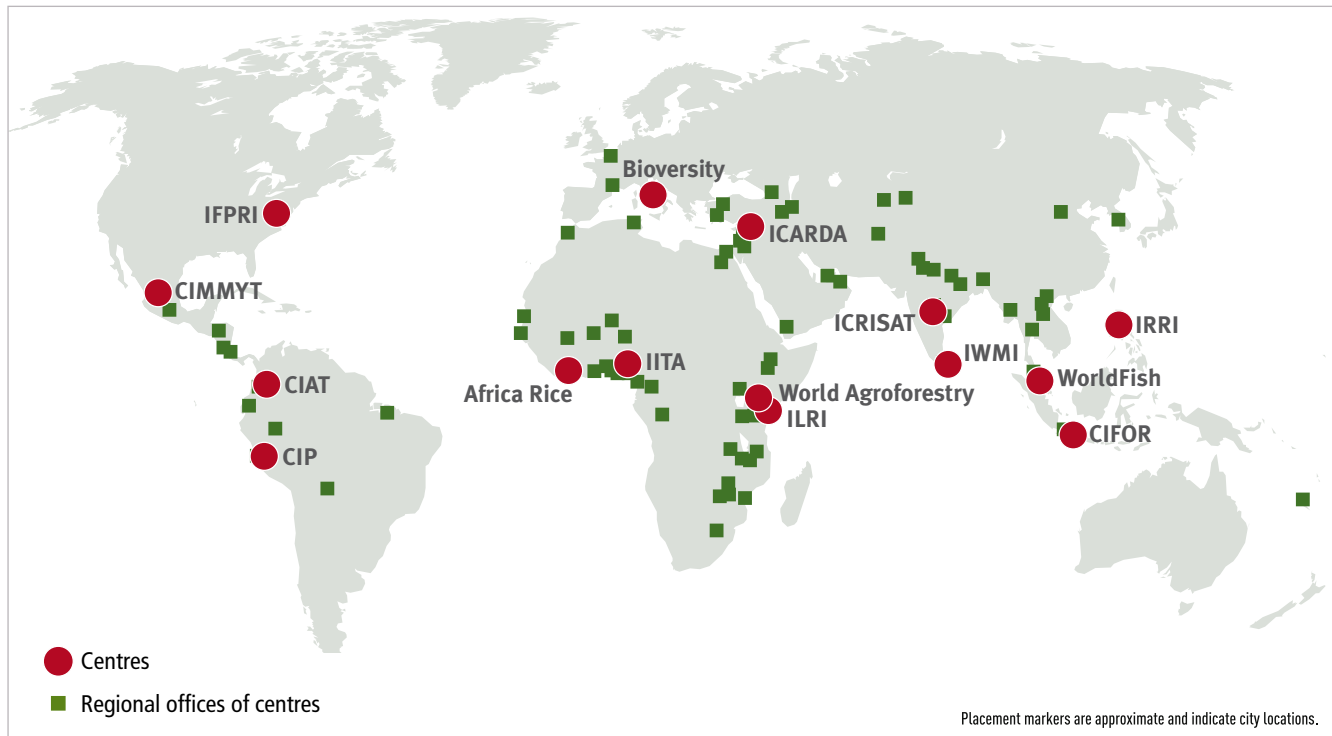
The contribution of agriculture itself to climate change is often overlooked. Current

practices, including the conversion of forests and grasslands for crops and pasture, result in significant releases of greenhouse gases – the Intergovernmental Panel on Climate Change (IPCC) estimated that 31% of total emissions in 2004 came from agriculture and forestry. This clearly needs to be addressed in mitigation strategies.

The climate is changing, and agricultural systems must also change if we are to avoid catastrophe. Farming, fishing and forest communities will need to adapt their livelihood systems, while mitigation efforts must address both the contribution of agriculture to the climate change problem, and the great potential of different resource management practices in reducing greenhouse gases in the atmosphere. The changes that are needed will be many and diverse. They will happen at the local level, tailored to local circumstances and ecosystems, and chosen and managed by the communities



Agriculture is under threat from climate change. Neil Palmer/CIAT.



Locations of the CGIAR centers and their regional offices. The five Challenge Programs – Climate Change, Agriculture and Food Security; Generation; HarvestPlus; Sub-Saharan Africa; and Water and Food – also operate across diverse locations, too many to include on the map.

themselves. They should have immediate benefits for the communities, as well as long-term benefits that future generations will enjoy. They must be based on sound science, and enabled by effective policy at all levels. They will build on the wealth of knowledge that already exists, and the new directions that research must now take to meet this enormous challenge.

The wealth of knowledge that already exists includes the results of more than three decades of research under the Consultative Group on International Agricultural Research (CGIAR). The 15 research centres supported by the CGIAR, and their many partners, have been working over this period to help poor farming, fishing and forest communities achieve sustainable livelihoods in the face of variable and uncertain weather. The accumu-

lated experience and expertise can be applied to address the additional threat posed by a changing climate.

Indeed, climate change provides a massive and urgent incentive to intensify efforts to disseminate the fruits of this research, and to continue developing adaptation and mitigation options. At least in the near years, the benefits of adopting many of the existing technologies – such as improved crop, soil and water management practices and stress-tolerant varieties – could be sufficient to override the negative impacts of climate change. And the immediate benefits, in terms of improved food security, livelihoods and environmental security, make this a ‘no regrets’ approach – these changes are worthwhile whatever happens to the climate. At the same time it is logical that



Climate change has the potential to act as a 'risk multiplier' in some of the poorest parts of the world. Stevie Mann/ILRI.

learning to cope with weather variability today paves the way for adapting to climate change tomorrow.

But climate change also promises new and unprecedented challenges, and demands new and urgent efforts to meet these. We need to take rapid strides forward in understanding what is going to happen to our farming, fishery and forest systems as the climate changes; the interactions that will occur with other global changes that are also under way; and within this complex and dynamic situation, the trade-offs we may face between food security, livelihoods and environmental security. We need to develop new and inventive responses to what is likely to be the most complex challenge that the world's food production systems have ever faced. To do this, we need new ways of working, new non-traditional partnerships

and truly integrated approaches. And we need much better communications between all stakeholders, so that decision making at all levels is based on the best knowledge available.

These needs provide the drive behind a new initiative led by the Alliance of the CGIAR Centers and the Earth System Science Partnership (ESSP). The Challenge Program on Climate Change, Agriculture and Food Security (CCAFS), which will launch in early 2010, unites the world's best researchers in agricultural science, climate science and earth system science to address the climate change–food security problem. The transformative research programme provides a framework for these communities to work together and, by doing so, to go beyond their traditional boundaries and open up new and unique possibilities in the search for solutions.

We can isolate some critical challenges that agriculture will face as the climate changes

Climate change and agriculture

There is a great deal of uncertainty about climate change, but there are some certainties. Average global temperatures are rising, and will continue to rise over the coming decades, whatever mitigation measures are taken, because of stocks of greenhouse gases already in the atmosphere. These rising temperatures are already having measureable impacts, on glaciers and ice caps, sea levels, and rainfall patterns, and these impacts will also increase over the next decades. The ultimate temperature rise will depend on mitigation measures put in place to limit emissions over the coming years. At this point in time, average temperatures are 0.7°C above pre-industrial levels; scenarios published by IPCC predict temperature rises of up to 4.5°C or higher by 2080, depending on a range of factors and pathways that human development may take. Many believe that a rise of 2°C is the threshold beyond which impacts are likely to be severe, and dangerous to environmental systems.

Mitigation measures are obviously critical to contain the damage, and changing agricultural and land use practices have a major role to play. Forestry, for example, accounted for some 17% of greenhouse gas emissions in 2004, according to IPCC. But if deforestation can be halted, reforestation initiated, and existing forests managed more sustainably by communities, forests could become part of the solution instead of part of the problem. Soils can be better managed to store carbon, while agroforestry is also an underutilized mitigation option. Biofuels are a complex issue at the moment. They have potential for reducing greenhouse gas emissions by

replacing fossil fuels; but their production has its own environmental costs, and may compete with that of food and feed. Research into biofuel development should clarify the issues, and allow production of biofuels in an environmentally sustainable way that also benefits the poor. These, and other promising mitigation options linked to agriculture, land use and natural resources management, are explored further below.

The results of mitigation efforts, in terms of reduced emissions and retained carbon and corresponding slowing of temperature rise, will not be evident for decades. But many of the options that relate to developing country agriculture and natural resources management will have immediate development benefits. Beyond 'no regrets', these are win-win opportunities that the world should not miss.

Whatever mitigation efforts are made, climate change is already happening, and temperatures will continue to rise during the coming years. It is not known exactly what will happen where, but the impacts we are beginning to see will intensify. These changes will happen at the same time as, and will interact with, the impacts of other global trends such as population growth, urbanization, increasing demands for water, over-exploitation of ecosystems, and shifts in world economics. If we are to understand real-life impacts, and develop meaningful responses, we must look at climate change and agriculture within this global system. The challenge is dynamic and multifactorial; the responses – the adaptation options that will allow people to manage this challenge – will have to match.



Forestry accounts for around 17% of greenhouse gas emissions. CIFOR.

We can isolate some critical challenges that agriculture will face as the climate changes. Many of these are amplifications of the substantial challenges that the current climate already imposes; water availability is at the top of the list. Already scarce in many regions, increasing demand and competition for water will combine with changing and less predictable rainfall and river flows. In Asia, changes in the monsoon rains and in glacier and snow melt are probably the greatest threats. In Africa, where so many people rely directly on the rain for their food and livelihoods, any changes to rainfall present a major risk. Indeed the IPCC's

Fourth Assessment Report suggests that some African countries may see yields from rainfed agriculture fall by as much as 50% by 2020, if production practices remain unchanged. Water quality is also at stake – saline water will increasingly affect agricultural systems due to seawater intrusion, over-exploited aquifers and unsustainable irrigation practices.

Higher temperatures will challenge many agricultural systems. Plants are sensitive to high temperatures during critical stages such as flowering and seed development. Often combined with drought, high temperatures can mean disaster to farmers' fields. Raised

The costs of climate change

A recent study by the International Food Policy Research Institute (IFPRI), titled 'Climate change: Impact on agriculture and costs of adaptation', highlighted some of the anticipated costs of climate change:

- ▶ 25 million more children will be malnourished in 2050 due to climate change without serious mitigation efforts or adaptation expenditures
- ▶ Irrigated wheat yields in 2050 will be reduced by around 30% and irrigated rice yields by 15% in developing countries
- ▶ Climate change will increase prices in 2050 by 90% for wheat, 12% for rice and 35% for maize, on top of already higher prices.
- ▶ At least US\$7 billion a year are necessary to improve agricultural productivity to prevent adverse effects on children.

carbon dioxide levels also have implications for crop plants, although impacts are complex and need further research.

Fishing communities are equally vulnerable. Water temperatures and acidity will change, as well as sea levels, upwellings and ocean currents. Impacts on marine ecosystems, particularly coral reefs, could be devastating; while aquaculture will be challenged by increasing temperatures and extreme events, and marine aquaculture also by environmental hazards such as harmful algal blooms.

Many pests and diseases of crops, animals and humans are sensitive to climate, and we can expect these to change in currently unpredictable ways. Some will become prevalent in areas where they were previously unknown, when the climate becomes favourable in those areas. The danger is that there is usually low immunity to a disease, and poor knowledge of pest or disease management, in areas where they have not occurred before.

Natural ecosystems are equally at risk from climate change. The natural environment is not static, and ecosystems have evolved and

adapted to gradually changing environmental conditions throughout history. A fundamental challenge of climate change is its rapid pace – and plants and animals that cannot quickly adapt to new conditions or relocate to new areas will become extinct. As well as destabilizing vital ecosystems, this also erodes the genetic base for future crops and livestock.

The impacts of climate change will not be felt evenly across the world, and may not all be negative. Some agricultural systems, mainly at higher latitudes and higher altitudes, may benefit at least in the short term from higher temperatures. Some dry areas may get more rainfall. But the most vulnerable – the many millions of people who survive by rainfed agriculture in the drylands of Africa, the millions more who make up the world's small-scale fishing communities, and those who make their livelihoods in low-lying regions like the Indo-Gangetic Plains, for example – look likely to face some of the most severe impacts, which will probably overwhelm their current coping capacities.

Climate change threatens agriculture, yet it also brings an opportunity – one which the world cannot afford to miss

A critical juncture

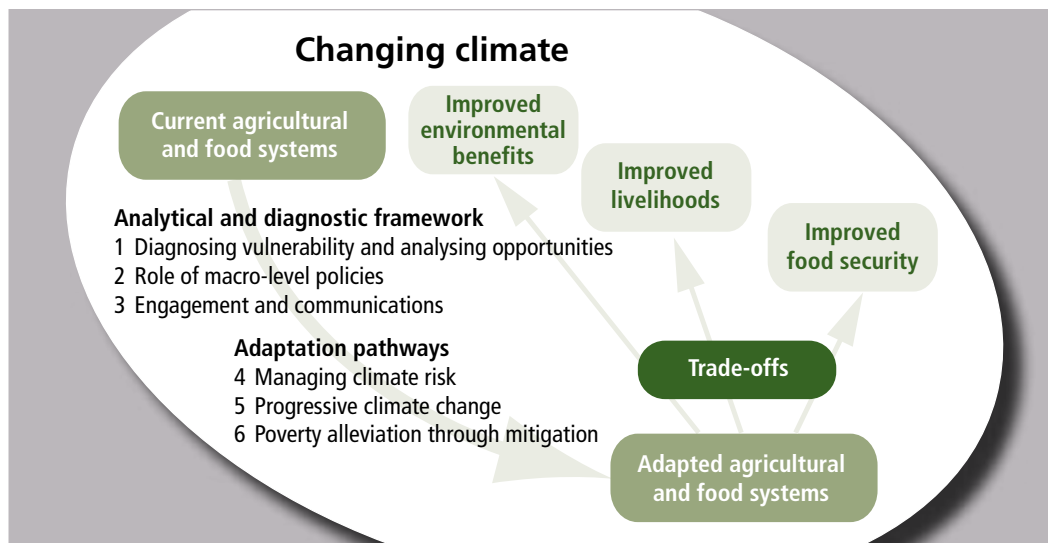
Climate change threatens agriculture, yet it also brings an opportunity – one which the world cannot afford to miss. The products of international agricultural research have great potential for much wider adoption than has been achieved so far – and their adoption will build the resilience of millions of people to weather variability and uncertainty today, and to future climate change. Some will also contribute to mitigation of climate change. Drought-, heat- salt- and flood-tolerant crop varieties, new ways to irrigate crops and better ways to manage soils are just some

of the technologies that hold great promise to help farmers today, and into the future. Livestock keepers can choose adapted breeds, and alternative feeds that do not depend on crops, among many other options, to reduce their vulnerability. There are many innovations to improve the sustainability of fisheries, forests and water supplies. Some of these are described in more detail in the following sections.

Bringing the products of more than three decades of research into use, and quickly, will be a tremendous challenge. It will depend on



We are at a critical juncture for agriculture. ICRISAT.



The CCAFS Challenge Program. Research under the six themes will help current agricultural and food systems adapt to a changing climate, while managing trade-offs between food security, livelihood and environmental goals.

the commitment of enlightened policy makers, considerable communications efforts, effective targeting and adequate resources. If successful, it will bring huge benefits to poor and vulnerable communities, immediately and into the future. But as dangerous climate change threatens, it will not be enough. We need to stay ahead of climate change – and to do that we need to go beyond current knowledge, and push agricultural science to new frontiers.

The next step must be a comprehensive framework that pulls together and integrates what is known about the climate system, the way it may change in the future, and the associated impacts on agro-ecosystems, the livelihoods of those who depend on them, and food security. While much is known about many components, no integrated framework exists. The new CCAFS Challenge Program offers this framework. As well as developing new approaches and new responses to the climate change–food security problem, it will also provide an overarching programme to support the CGIAR centres in their climate change-

related endeavours, and help consolidate their efforts. Links with the ESSP will bring a critical new set of skills into the agricultural research arena, for example expertise in climate modelling, climate forecasting and downscaling of forecasts, and modelling to inform decisions about trade-offs. Over the next 10 years, the Challenge Program aims to build the foundations for responsive, adaptive agricultural systems that reduce vulnerability to current variability and uncertainty, and pave the way for the successful management of long-term changes.

The next sections of this report describe the two key thrusts that are now under way to address the climate change, agriculture and food security problem: the existing knowledge that holds great promise for managing weather variability in agricultural systems and reducing the impacts of agriculture on the global climate, which must now be translated into action; and the future research that will close critical knowledge gaps, develop new ways of working, and build new strategies for change.

A framework for action



There is no time to waste in addressing climate change, agriculture and food security. We must move to a deeper understanding of the problem as quickly as possible. Where we have already identified ways forward, and as we identify new ways, we must become more efficient in implementing them. There is no place for duplication of effort, for absent or weak policy, or for poor communications – each of these potential limitations must be dealt with decisively, and soon.

This section outlines a framework to support the successful implementation of adaptation and mitigation options. Its three pillars are communications, policy and improved understanding of the problem. Without serious attention to all three, any adaptation and mitigation efforts will fail to reach the scale required to avert a looming catastrophe.

Understanding the problem, targeting the solutions

The first step is to understand the problem; but this in itself is a major challenge. While climate scientists are working to understand what is going to happen to the climate, there is currently much uncertainty in their projections. Predicting how these uncertain changes will affect agricultural and food systems is thus extremely difficult. What we can do, however, is look at the vulnerability of systems, in the light of possible changes to the climate. Vulnerability depends on both sensitivity of the system to the climate, and the adaptive capacity of the population.

Several studies have looked at the sensitivity of specific crops to projected changes in the climate, to assess vulnerability of systems based on these crops (see page 10). Significant reductions in yields of these crops are the general finding. Another study looked at the sensitivity of wild species related to some of the major food crops – an important gene pool for future crops (see page 11). Again, results indicate significant negative impacts.

Other studies have looked at the vulnerability of whole agricultural systems, taking both sensitivity of systems and adaptive capacity of communities into account. In sub-Saharan Africa these studies have identified 'hotspots of vulnerability'; while the vulnerability of national economies has been highlighted in fisheries studies (see page 11).

Vulnerability assessments and mapping provide a starting point for interventions. While we cannot at this point in time quantify the exact risk – we do not know exactly what will happen where – we can nonetheless work to enhance the adaptive capacity of the people and communities who are most vulnerable, and to reduce the sensitivity of their livelihood systems.

But we need to do more. Most of the mapping and vulnerability studies have been at regional scales, masking enormous variation at the local level. While such regional studies are useful for planning at these scales, planning for better adapted livelihoods can only be done at a much more local level. A challenge for the next stage of research will be downscaling of vulnerability assessment and mapping exercises.

We also need to better understand the interactions of climate with other drivers

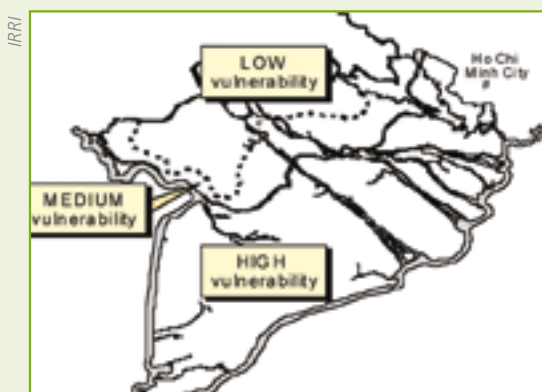
Assessing and mapping vulnerability

Maize in sub-Saharan Africa and Latin America. Scientists at the International Center for Tropical Agriculture (CIAT) and the International Livestock Research Institute (ILRI) have taken outputs from climate simulation models and data from various sources to simulate the growth, development and yield of maize crops over sub-Saharan Africa and Central and South America. The results showed an aggregate yield decline by 2055 for smallholder rainfed maize production of 10%, representing an annual economic loss on the order of US\$2 billion.



CIMMYT

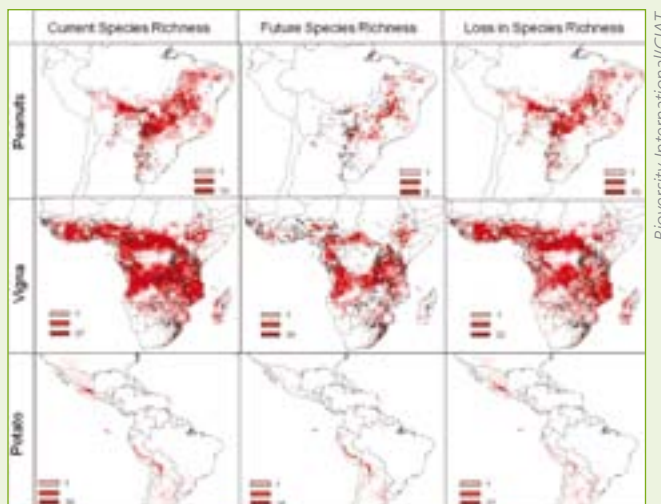
Wheat in the Indo-Gangetic Plains. Wheat is a crop of temperate climates, and rising temperatures may make many currently important wheat areas too hot for the crop. A study from the International Maize and Wheat Improvement Center (CIMMYT) details possible climate shifts in the Indo-Gangetic Plains of South Asia, a region of 13 million hectares that extends from Pakistan across northern India, Nepal and Bangladesh, and which grows 15% of the world's wheat. According to the study, by 2050 more than half of its area may become heat-stressed for wheat, with a significantly shorter season for the crop.



Rice in the mega-deltas of Asia. The Mekong and Red River Deltas in Vietnam, the Irrawaddy Delta in Myanmar and the Ganges–Brahmaputra Delta in Bangladesh and India are vital for world rice production. But the impacts of climate change – increased flooding and salinity – pose a major threat. The International Rice Research Institute (IRRI) and partners have mapped the hydrological impacts of projected sea level rise within the Mekong Delta, and plan to use this information to define adaptation strategies based on improved rice cultivars and management options.

Potatoes and sweetpotatoes. The International Potato Center (CIP) has modelled the impact of climate change on potato production with and without adaptation strategies. Potato yield reductions in the tropics and subtropics were 20–30%; these were mitigated with adaptation strategies including stress-tolerant varieties and improved crop management. CIP and partners have also mapped drought- and high temperature-prone potato and sweetpotato cropping areas and have identified regions with high vulnerability to climate change effects.

Crop wild relatives. Scientists from Bioversity International, CIAT and IRRI used a computer simulation to quantify the impact of climate change on the geographical distribution of wild species related to three major food crops: cowpea, peanut and potato. They estimated that 16–22% of the wild relatives of the three crops could become extinct by 2055 and that the distribution of the remainder could be reduced by more than half. The impacts on peanut wild relatives are predicted to be especially severe – about half of the 51 peanut-related species studied could become extinct, and the distribution of those remaining could decline by more than 90%.



Hotspots of vulnerability in Africa. A recent study carried out by ILRI in sub-Saharan Africa used climate models to examine four different scenarios for the region to 2050. The most vulnerable areas were found to be the West African Sahel; the rangelands, Great Lakes and coastal areas of Eastern Africa; and the drier zones of Southern Africa. Researchers next characterized the vulnerability of those and other areas in terms of various biophysical and social factors, such as soil degradation, market access and HIV prevalence, and then integrated the results with those for climate change. The combined results indicate which agricultural systems, by country, constitute 'hotspots of vulnerability'. Published in 2006, these results have already been used in several influential studies, including the UK Government's Stern Review on the Economics of Climate Change.

Fisheries systems. WorldFish researchers and partners recently examined the vulnerability of 132 national economies to expected climate change impacts on their capture fisheries. Highly vulnerable nations are primarily in Asia, Africa and Latin America and include many least developed countries, where fisheries are also important to the nutrition and livelihoods of many people. In a separate study, WorldFish is studying how fisheries systems within nations across 20 large marine ecosystems may respond to climate change under different population, trade, economic and policy scenarios. Meanwhile, in the Coral Triangle spanning Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands and Timor-Leste, where climate change poses serious threats to coral reefs, WorldFish is assessing national and local dependence upon reefs and the implications for social vulnerability to climate change.

Forests and forest communities. The Tropical Forests and Climate Change Adaptation project, led by the Center for International Forestry Research (CIFOR), is developing methodologies to assess the vulnerability of forests, and forest communities, in order to guide adaptation strategies for forest-based development sectors. Methods and tools have been trialled in Ghana, and vulnerability risk maps have been developed using changes in forest cover as proxy for changes in the supply of forest goods and services. Projected degradation under 'business as usual' suggest a total loss of 95% of the forest–savanna transition zone, 81% of the savanna zone, and 77% of the high forest zone by 2050.

of change in agricultural systems, as well as broader development trends. Population growth, globalization of markets, water pricing, and development investment policy, for example, will all play their part in future food systems, alongside climate. And the changes we make to deal with climate change, both adaptation and mitigation, will themselves have impacts on systems.

The first research theme of the new Challenge Program, 'Diagnosing vulnerability and analysing opportunities', will carry forward work on some of these outstanding needs, while other research groups will also pursue a better understanding of climate change impacts and vulnerability within their mandated areas. As gaps are filled, we will see more effective priority setting and research resource allocation, increased uptake of appropriate options whose trade-offs are understood, and more informed regional, national and local decision making.

The policy challenge

Policy that facilitates change – for both adaptation and mitigation outcomes – is going to be critical to successful responses to climate change. There are three main challenges for agricultural research: producing the evidence to guide policy; engaging with the policy world to ensure that policy responds to the evidence; and understanding the real impacts of such policies and policy change. A fourth challenge lies with policy makers: providing a fast enough response to meet the urgency of the situation.

Producing evidence is the business of research and, as this report shows, efforts have been steadily intensifying to provide evidence for climate change adaptation and mitigation measures within agricultural and food systems. Similarly, engaging with policy makers has received much more attention in recent years.

Policy that facilitates change – for both adaptation and mitigation outcomes – is going to be critical to successful responses to climate change

As the climate change debate has escalated, agricultural researchers have stepped into the arena and learned to put forward their arguments to influence outcomes. The major meetings of leading actors in the climate change debate have increasingly seen CGIAR presence over the last few years. This year, for example, the CCAFS Challenge Program held a side event at the United Nations Commission for Sustainable Development (CSD-17) meeting in New York in May; in the same month the World Agroforestry Centre and the Common Market for Eastern and Southern Africa (COMESA) held a similar event at the 3rd Special Session of African Ministers of Environment on Climate Change in Nairobi; and IFPRI and CIFOR held side events at the United Nations Framework Convention on Climate Change (UNFCCC) Subsidiary Body for Scientific and Technological Advice (SBSTA) 30th Session in Bonn in June, at which WorldFish also contributed to a side event on Climate Change and the Oceans. The highest profile climate change meeting is probably the UNFCCC's annual Conference of Parties (COP), and since 2007 CIFOR has organized a Forest Day in parallel with the main meeting. This year an Agriculture and Rural Development Day will also be held, organized by a consortium of the major global players including the CGIAR.

IFPRI is the CGIAR's policy arm, and aims to link CGIAR research with policy action (see page 13). IFPRI also carries out policy research, and is currently analysing the complex interrelations between climate change and agricultural growth, food security, and natural resource sustainability.

Influencing policy

IFPRI briefs. IFPRI has prepared a set of 13 briefs that set ‘An agenda for negotiation in Copenhagen’. The briefs present information on some of the key areas of CGIAR work on climate change adaptation and mitigation, in a format targeted at policy makers. Each brief ends with ‘suggested negotiating outcomes’ that clarify the major points for debate. A summary sets out the three overarching needs for agriculture in the face of climate change:

1. *Investments.* There must be explicit inclusion of agriculture-related investments, especially as part of a Global Climate Change Fund.
2. *Incentives.* There must be a deliberate focus on introducing incentives to reduce emissions and support technological change.
3. *Information.* There must be solid commitment to establishing comprehensive information and monitoring services in soil and land use management for verification purposes.

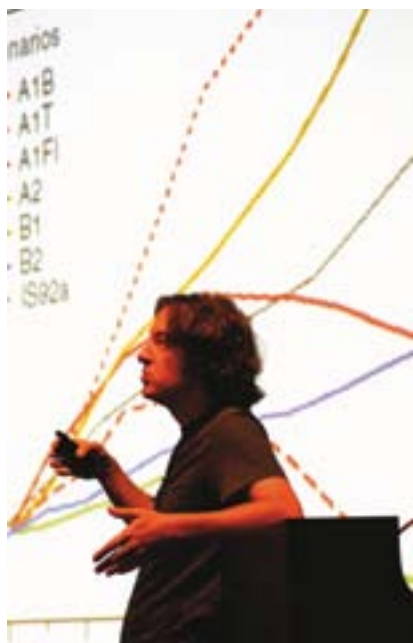
Tools for water policy makers. IWMI has developed several tools to help water management decision making. PODIUM is an interactive scenario analysis and policy planning tool that helps explore the interactions of water, food security and environment at the national level, in light of changes such as increasing population and changing diets, and assesses trade-offs. It is intended to foster dialogue and stakeholder participation, and provide a basis for multi-sectoral planning and analysis. Another model, WATERSIM, works at the global level. It can be used to analyse, for example, trade-offs between irrigated and rainfed agriculture, impacts of international agreements on water use at regional and basin level, and impacts of alternative investment strategies in water infrastructure and agriculture.



IWMI

Guiding policy on carbon markets. Current carbon markets focus almost entirely on afforestation and reforestation projects, and the proposed Reducing Emissions from Deforestation and Forest Degradation (REDD) scheme also fails to acknowledge the value of carbon sequestration through natural resource management options outside forestry. Unless this changes, many African nations will be effectively locked out of these markets. The World Agroforestry Centre is working with COMESA to promote an approach that considers greenhouse gas emissions from Agriculture, Forestry and Other Land Uses (AFOLU). Two policy briefs have been produced – ‘The case for investing in Africa’s biocarbon potential’ and ‘Africa’s biocarbon interests – Perspectives for a new climate change deal’.

Effective policy will be crucial in the coming years as we address the climate change threat. But policy is complex and multilayered, and we will need to better understand the interactions and the real impacts of policies to be successful. Policies may have unintended effects, or at the least, there may be trade-offs. Climate-focused policy may lead to unintended and potentially contrary outcomes on rural livelihoods and environmental systems – for example, policy that aims to climate-proof food production systems by developing large-scale irrigation drawing on rivers may inadvertently destroy livelihoods of fishing communities downstream by altering streamflow. Reconciling poverty alleviation, agricultural and rural development, economic growth, sustained ecosystem services, and climate change adaptation and mitigation, among other global needs, will be an enormous challenge for policy makers. Focused policy research is needed.



Presenting evidence to policy makers: Andy Jarvis of CIAT. Neil Palmer/CIAT.

The second research theme of the CCAFS Challenge Program is titled ‘Unlocking the potential of macro-level policies’. It will address some of the fundamental policy questions that need to be answered if we are to untangle the complex policy web and see successful outcomes, such as:

- ▶ How do different climate policies affect developing country agricultural growth, food security, poverty and environmental sustainability?
- ▶ How could local-level technical and policy interventions for adaptation and mitigation be fine-tuned to be more effective in the context of macro-level policies?
- ▶ How could the macro-policies that drive globalization be adjusted to both minimize adverse environmental impacts and promote rural livelihoods?

Rethinking engagement and communications

Engagement and communications – the process by which knowledge informs action – is a complex area and one that has not always been given the attention it deserves. The result is that ‘useful’ science has often failed to enter into use, and policies do not always reflect evidence. But this is changing. Researchers and other stakeholders are learning new methods that can close gaps between knowledge and action, while a plethora of new tools is opening up new avenues for information exchange.

Climate change raises the bar for communications. The complexity of the issues, and the need for information and understanding across society, presents a unique challenge. Agriculture adds its own layer of complexity, in that it is intensely local, and requires that information be relevant and useful at that level. This also means that two-way communications are critical.

Researchers and other stakeholders are learning new methods that can close gaps between knowledge and action

Indeed, collaborative research and learning is the way forward to get research into use. New ways of working will see researchers defining outcomes – changes in behaviour, policies and practice – jointly with stakeholders at the beginning of projects. This is one of seven ‘principles’ that have been identified as important for linking knowledge to action (see page 16). Strong and diverse partnerships are another. Public–private partnerships in particular are increasingly recognized as a way to facilitate innovation and uptake of technologies. Knowledge exchange networks are another form of collaboration that will prove essential as rapid information exchange becomes critical. Ultimately, an innovation systems approach is needed, that starts with strategic partnerships and learning platforms, and focuses upon providing knowledge and support to the institutional changes needed for uptake and scaling out of technologies.

New tools that facilitate collaboration are appearing almost every day. Advanced web tools, particularly social media tools, look set to play an important role, for example in self-organizing information exchange groups. Mobile phones have a huge role to play in future communications, both for getting information (such as climate forecasts) to individuals, and also allowing individuals to feed information into larger exchange systems. Meanwhile the more traditional media, like video and radio, remain valid communications tools (see page 17).

The third theme for research in the new Challenge Program, ‘Enhancing engagement and communication for decision-making’, will develop and apply these new tools and new ways of working to the unique communications challenge that climate change and agriculture together present.



Continuing dialogue between researchers and decision makers is key. IWMI.

Understanding the information needs of the different stakeholders will form the basis of research, because information will only be used if it is relevant to the problems facing people, as they perceive them. Implicit in this is a recognition of the different values, interests and perspectives of the diverse stakeholder groups and of researchers. Research will also draw upon experiences of how farmers and communities already adapt to weather variability and extreme events, and assess the role and relevance of local knowledge and experience for adaptation to the uncertain and changing conditions of the future. Continuing dialogue between researchers and decision makers will be the key, providing a mutual learning opportunity and ensuring that knowledge produced is both useful and used.

Communications for change

From knowledge to action. A recent study by researchers at ILRI defined seven broad principles that promote success in linking knowledge with action:

1. **Problem definition:** Define the problem in a collaborative and user-driven manner.
2. **Program management:** Adopt a project orientation and organization and appoint dynamic leaders accountable for achieving user-driven goals.
3. **Boundary spanning:** Use 'boundary-spanning' organizations, individuals and actions to help bridge gaps between research and research-user communities, construct informal arenas that foster producer–user dialogues, develop joint rules of engagement and define products jointly.
4. **Systems integration:** Recognize that scientific research is just one 'piece of the puzzle' and apply systems-oriented strategies.
5. **Learning orientation:** Design projects as much for learning as for knowing and to be frankly experimental; expect and embrace failures to learn from them.
6. **Continuity with flexibility:** Strengthen links between organizations and individuals operating locally, building strong networks and innovation/response capacity.
7. **Manage asymmetries of power:** Level the playing field by generating hybrid, co-created knowledge.



Sharni Jayawardena/ILWMI

Networks. Networks that link stakeholders help new technologies reach farmers quickly. The Latin American and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA by its Spanish acronym) is an example. Coordinated by CIAT, CLAYUCA has members from the public and private sectors in 16 countries, all working to improve the generation and exchange of new cassava-related technologies. The initiative has been responsible for the development, adaptation and transfer of several technological platforms for cassava production, processing and utilization that are helping farmers increase yields and incomes and improve livelihoods.

Public–private partnerships. Public sector organizations in several countries – Brazil, India, Kenya, Mexico and South Africa, for example – are becoming increasingly reliant on collaboration with the private sector and civil society. These results-oriented interactions improve the efficiency and effectiveness of research, extension and education services; enhance access to new products and services that target the rural poor; and foster greater pro-poor innovative activity in the food and agricultural sector. IFPRI is carrying out research on how such collaborations work – in particular how they facilitate and stimulate innovative behaviour.

Blogging the climate. The Rural Climate Exchange blog was launched by the CGIAR in June 2009, to share information and knowledge on climate change. So far the blog has focused on issues such as putting rural people at the centre of the international climate change negotiations, the prospect of farmers transitioning from crop production to raising livestock, and the role of agriculture in the UNFCCC negotiations. There has been ‘live’ blogging from major events, such as the World Agroforestry Congress in August 2009. The blog currently receives an average of just over a thousand visits per month, and the figure is rising steadily.



IWM/



Video and mass media. Conventional media such as radio and video have an important part to play in communications of the future. The Africa Rice Center, as part of a Rice Rural Learning Campaign, is combining local language educational videos with mass media to train farmers on various facets of rice production and processing. The videos, which are disseminated through mobile cinema vans or local organizations, have been translated into 20 African languages and have so far been viewed by about 130,000 farmers across Africa. Partner organizations in various countries are combining the videos with radio programming to reinforce the lessons and knowledge. In Guinea for example, Radio Guinée Maritime has aired interviews with farmers involved in the training, reaching some 800,000 listeners.

Mainstreaming climate risk management into livelihood strategies will help farmers cope with weather variability and uncertainty

Strategies for change

Widespread adoption of adaptation and mitigation strategies that will reduce the vulnerability of farming, fishing and forest communities depends on investment and advances in the three themes described above. The following sections describe the building blocks of these strategies.

Adapting now

We do not need to wait for the uncertain conditions of the future to evolve – the climate today is already having significant negative impacts on the lives and livelihoods of poor people around the world. Indeed, droughts and floods are far from new phenomena, and farmers have developed various ways of coping with them, and other weather extremes, over the centuries. But poverty limits options, and the risk that the climate presents to agriculture plays a significant part in keeping farmers, and their families, in poverty.

Without the back-up of insurance, small-scale farmers can lose everything if there is a weather 'shock'. To survive, they will probably have to sell any assets they possess, such as animals or farming tools, and when it is over they will be in a much worse position than they were before. The impacts of an extreme weather event can therefore last much longer than the actual event.

But even if the weather is favourable, the threat of possible bad weather is enough to limit growth. Poor farmers often choose not to invest in new technologies and opt for less

risky but also less profitable crops, even when climate conditions are good. In addition, the climate risk limits their access to credit, because lenders know there is a high chance of default on the loan. So even if they wanted to invest in inputs to improve their farming system, they would probably be unable to. Although a weather shock may happen only one year in five or six, the threat limits growth in all years.

This is the climate–poverty conundrum, and it has been one of the most intractable problems limiting development. It has also clearly limited the uptake of agricultural innovations. Climate change will only add to the problem, and if the conundrum is not addressed, significant development reversals look very likely.

The emerging discipline of climate risk management (CRM) may hold some answers. CRM advocates the systematic use of climate information in planning and decision making at all levels, use of climate-informed technologies that reduce vulnerability to weather variability and uncertainty, and climate-informed policy and market-based interventions that transfer risk from vulnerable populations. CRM not only offers protection against the impacts of bad weather, but also opportunities to capitalize on favourable weather. It is applicable across climate-sensitive sectors, including health and water resources as well as agriculture and food security, and across all levels, from national adaptation plans to household coping strategies.

Feeding climate information into climate-limited livelihood systems holds a great deal of promise to improve the resilience of these

systems. A handful of projects have turned this promise into reality. In Mali, the national meteorological service has been providing climate information to farmers in the form of forecasts and related advice for over two decades, and the farmers have also learned to monitor the weather themselves to improve their decision making. Results are significantly higher yields and higher incomes compared with non-participating farmers (see page 20).

A broad range of tools and options come under the CRM umbrella, some familiar, others new. Index-based insurance is one of the newer options that could help transfer the climate risk from vulnerable populations to financial markets. Several pilot projects have demonstrated its feasibility, and there is currently a lot of interest in this approach (see page 20). There are however some significant challenges to its widespread deployment which need to be addressed. For example index insurance, and many other CRM tools, depend on quality climate data that are currently often lacking, or not easily accessible, in developing countries. A step was taken in the right direction recently, at the World Climate Conference-3 in September 2009, with the establishment of a Global Framework for Climate Services that aims “to strengthen production, availability, delivery and application of science-based climate prediction and services”.

Climate forecasts are an important CRM tool, and as climate science advances and they become more skilful, they offer great potential to help farmers manage the climate risk. Seasonal forecasts in particular are potentially very useful, but they currently seldom reach poor farmers in a useable form, and within a comprehensive package of information and support. Planning for the season ahead could be vastly improved; and the uncertainty that all forecasts contain could be managed with a tool such as index-based insurance. In



Even the threat of bad weather is enough to limit growth. Neil Palmer/CIAT.

other words, farmers prepare for the higher likelihood scenario, and insure against the lesser likelihood scenario.

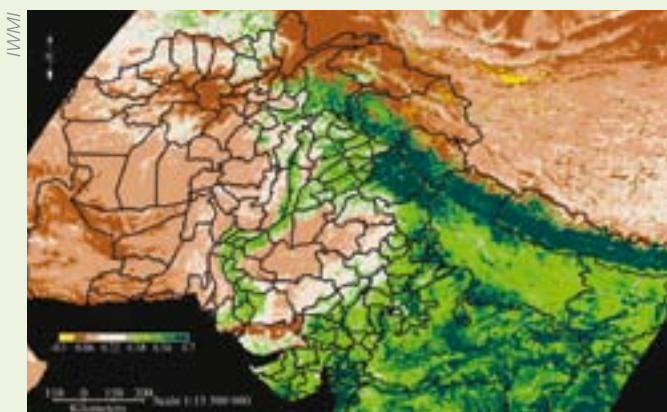
Mainstreaming CRM principles into livelihood strategies will help farmers cope with weather variability and uncertainty. And coping with such variability today inevitably paves the way for adapting to climate change tomorrow. CRM is a natural complement to the climate-responsive technologies that agricultural research has produced – indeed, in some cases it could provide the ‘missing link’ that has limited their adoption so far.

Incorporating CRM into agricultural systems is the drive behind the fourth theme of the CCAFS Challenge Program, ‘Adaptation pathways based on managing current climate risks’. Research will address knowledge gaps, for example those related to targeting, package design, institutional challenges to implementation at scale, and the implications of advance information. The aim is to incorporate CRM into agricultural development strategies, and ensure that the necessary climate services and support are in place.

Climate risk management in action

An agrometeorology project in Mali. Mali's national meteorological service launched a project some 25 years ago to provide climate information to rural people, especially farmers. The project was the first in Africa to supply climate-related advice directly to farmers, and to help them measure climate variables themselves, so that they could incorporate climate information into their decision making. Over the years, the project has evolved into an extensive and effective collaboration between government agencies, research institutions, media, extension services and farmers. Today, more than 2000 farmers are participating. Climate information is collected from diverse sources, including the World Meteorological Organization, the African Centre of Meteorological Application for Development, the national meteorological service, extension workers and farmers themselves. It is then processed and provided at three levels – seasonal forecasts, forecasts for the next 3 days, and 10-day bulletins that include information on the state of crops, water resources and weather conditions, as well as crop health issues, pastoral issues and agricultural markets. Data collected by the national meteorological service, as well as farmer testimonies, indicate significantly higher yields and incomes up to 80% higher for participating farmers. Farmers feel they are exposed to lower levels of risk and are therefore more confident about purchasing and using inputs such as improved seeds, fertilizer and pesticides.

Index insurance. Index insurance is insurance that is linked to an index, such as rainfall, temperature or crop yields, rather than actual loss. This approach solves some of the problems that limit access to traditional crop insurance in rural parts of developing countries. One key advantage is that transaction costs are lower, making index insurance financially viable for private-sector insurers and affordable to small farmers. The most common application so far is the use of an index of rainfall totals to insure against drought-related crop loss. Payouts occur when rainfall totals over an agreed period are below an agreed threshold that can be expected to result in crop loss. Unlike with traditional crop insurance, the insurance company does not need to visit farmers' fields to assess losses and determine payouts; instead it uses data from rain gauges near the farmer's field. As well as reducing costs, this means that payouts can be made quickly – a feature that reduces or avoids distress sales of assets. There are now several examples of index insurance in use around the world, including in India where it has been scaled up and is now bought by hundreds of thousands of farmers through both private sector and public schemes. ILRI is currently trialling an index-based livestock insurance scheme in Kenya, to protect against drought-related mortality during the short rain/short dry season spanning October 2009 to February 2010.



Drought monitoring and early warning. South Asia Drought Monitor is an evolving drought monitoring tool developed by IWMI. It uses freely available satellite data to monitor ground vegetation as an indication of drought progression. Reporting in near real time, the system currently covers Afghanistan, Pakistan and western parts of India. With further improvements, including building in weather forecasts, this could provide an effective early warning system for droughts, allowing early action to reduce impacts.

We have the knowledge right now to make vast improvements to agricultural systems – improvements that can compensate for the negative impacts of climate change

Adapting into the future

We have the knowledge right now to make vast improvements to the sustainability and productivity of agricultural and other natural resource-based systems in developing countries – improvements that can compensate for the negative impacts of climate change at least in the near years, and at the same time build resilience to more distant changes in the climate. There is no reason or excuse not to put this knowledge into action.

The sections below describe some of the changes that can be made. The divisions are largely artificial – real-life systems, and the people who manage them, address any number of these at any one time in an integrated way. A role of the CCAFS Challenge Program is to develop a more holistic approach to adaptation, working to integrate the different sectors, so that farmers, communities and policy makers are offered integrated solutions.

As the climate changes, there will be a spectrum of appropriate solutions, from targeted adjustments to existing systems to much more radical changes. While adopting drought-tolerant varieties of crops may be a sufficient response in some systems in the coming years, others may need to completely rethink their crops, or change to livestock keeping, or to another livelihood strategy. Solutions must also be dynamic – as the climate changes, the responses must change. It remains to be seen exactly how the climate will change in the coming decades, but we must be ready for whatever happens, with flexible responses based on sound science and backed by enabling policy and exceptional communications.



Agricultural systems must adapt as the climate changes. IRRI.

Water is the defining link between the climate and agriculture

Facing up to the water crisis

Water is the defining link between the climate and agriculture. But even without climate change, we are in serious trouble. Competing demands combined with mismanagement of this critical resource means that water availability has become an urgent issue facing farmers (and other users) the world over. And typically, the most extreme shortages are experienced by those least able to cope with them – the most impoverished inhabitants of developing countries. Climate change will exacerbate an already critical situation.

In developing countries, agriculture consumes 70–90% of total water use. With growing populations, and competing demands from other sectors, this is not sustainable. There is no alternative – more food must be produced using less water.

On the whole we know how to do this. There are many relatively simple and low-cost

technologies – some based on traditional water management techniques, others new – that can improve water use in agriculture, both rainfed and irrigated (see pages 23–24). Water harvesting, precision irrigation and multi-use reservoirs are just some of many options for eking out limited water supplies, while low quality water can be managed and used in certain systems.

Crucially, these and other sustainable water management options need to be embedded in improved stewardship of this shared resource. Improved management at the watershed level should focus on equity of access, recognizing multiple users and their interdependence in the face of limited water supplies. Only by using water much more efficiently, and considering other users in the chain, will conflict be avoided in the future.



Water is already a critical limitation for many poor people. Mutsa Masiyadima/IWMI.

New – and old – ways with water

Julie van der Blik/IWMI



Drip irrigation. IWMI is working with local partners on 'bucket and drip' irrigation systems. Water flows from a raised bucket into pipes with emitters scattered throughout the plot, which discharge the water into the soil near the plants by means of a slow-release mechanism. Requiring an investment of only about US\$5, these systems enable growers to apply just enough water to ensure good harvests. While IWMI is concentrating on southern Africa in this work, researchers at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are helping introduce drip irrigation in West Africa's Sahel region for the production of high-value vegetables and fruits.

Water harvesting. Farmers in West Asia and North Africa, inhabiting some of the driest regions on earth, have for hundreds of years practiced water harvesting. This involves diversion of scarce rainfall from large areas into small parcels containing crops and trees. International Center for Research in the Dry Areas (ICARDA) scientists are studying traditional systems for water harvesting, with the aim of helping refine and disseminate them more widely. In Syria, for example, mechanized construction of traditional micro-catchment ridges has permitted the expansion of water harvesting in degraded rangelands. Meanwhile, the WorldFish Center is working in sub-Saharan Africa to help develop governance systems to guide water harvesting at the watershed level.

Flexible water storage options.

Water storage – from groundwater, through soil moisture, small tanks and ponds, to small and large reservoirs – is going to be increasingly important for rural communities dealing with water scarcity, shorter rainy seasons and increasingly erratic precipitation patterns. Small, multi-purpose reservoirs offer a particularly valuable adaptation option. The Small Reservoirs Project, a Challenge Program on Water and Food (CPWF) project led by IWMI, is developing tools to help planners and stakeholders, particularly farming families, develop economically and environmentally sustainable small multi-use reservoirs and institutions for their communities.



Sanjini de Silva/IWMI

Sanjini de Silva/IWMI



Using wastewater. Wastewater is already used for food production in many resource-poor environments. As other water sources become less reliable and demand for food increases, wastewater will soon be seen as an asset not a problem. Irrigation with untreated, partly treated or diluted wastewater has environmental and health risks, but farmers use it because it is a reliable source (often the only source) throughout the year, and it often reduces or eliminates the need for fertilizer, among other reasons. IWMI is carrying out research in Pakistan, Ghana, Vietnam and Mexico, under a CPWF project, to reduce or eliminate the health risks and help policy makers and planners balance the needs of small farmers with the health of people and the environment.

Water policy under global change. A CPWF project led by IFPRI, Food and Water Security under Global Change, is working to understand the impacts of global change on agriculture and water resources at the global, national and river basin levels, to assess the effects of global change on water and food security in vulnerable rural areas of Africa, particularly rural Ethiopia and South Africa, and to identify adaptation measures that reduce the impacts of global change on these communities. The results will provide policy makers and stakeholders with tools to better understand, analyse and inform policy decisions for adaptation to global change.

Improving watershed management. In many situations, improved management of water requires not only actions by individual farmers but collective efforts to improve stewardship of this shared resource. Such approaches, requiring the empowerment of local rural institutions, are not easy to replicate on a large scale, but research done by IWMI suggests that 'irrigation management transfer' can be done. Similarly, ICRISAT has successfully promoted an integrated approach to watershed management in India and other Asian countries and is now beginning to transfer the innovation to Eastern Africa. An assessment of the impact of this approach in one watershed in India indicated that from 1998 to 2003 the use of new technologies, combined with traditional methods, almost doubled the incomes of small farmers, raised groundwater levels by 5–6 metres, expanded green cover from 129 to 200 hectares and more than doubled agricultural productivity.



IWMI

The breeding programmes of the CGIAR centres and their partners will continue to lead the way in developing new, adapted varieties

Crops for an uncertain future

The principles of crop breeding remain unchanged since humans first began domesticating plants for food thousands of years ago. Climate change simply alters some of the traits of interest. It also adds an urgency that demands use of the very best and latest that plant breeding science has to offer. And it argues an even stronger case for conserving agrobiodiversity, in genebanks and in farmers' fields.

Climate change focuses attention on several traits of interest, such as drought and heat tolerance. But at the same time, and particularly in light of the uncertainty of climate change, crop varieties must do much more. Farmers depend on their crops performing well in good years, so the need is for crops that are able to perform in difficult environments, but also produce high yields when conditions are more favourable. Breeding for vigorous root systems, for example, allows plants to capture scarce water.

Molecular biology has opened up the horizons for crop breeding, and will become increasingly important. Identification and selection of useful genes using molecular markers has become routine in plant breeders' laboratories. The use of biotechnology to genetically improve crops is still controversial, but the pressures on the world's agricultural systems may hasten its acceptance, with all the appropriate biosafety precautions in place.

However high-tech plant breeding becomes, it must draw on the genes that nature and evolution have provided as raw material. Yet agrobiodiversity is under threat. Of the approximately 50,000 plant species that are edible, we use no more than 50, of which 15 supply 90% of the world's food and just three – wheat, rice and maize – supply 60%. While breeding programmes have dramatically increased yields in these crops, they have further reduced genetic diversity, making them vulnerable to changing conditions.

Again, breeders can rise to this challenge, ensuring new varieties have the genetic diversity that climate uncertainty, and other variables such as changing pests and diseases, demand. The genebanks of the CGIAR hold approximately 600,000 genetically diverse plant samples – improved crop varieties and traditional landraces from farmer selection, but also wild species related to crops – that are available for breeding programmes. This gene pool will prove invaluable in the race to adapt farming systems to future climates. But farmers' fields also hold important agrobiodiversity and, unlike that in genebanks, this is a changing and evolving gene pool. 'Evolutionary' breeding programmes capitalize on this, increasing the probability of recombination by growing diverse populations at multiple locations and leaving them to evolve. Researchers and farmers can select from the plots, but the main population continues to evolve, becoming a unique source of continuously adapting genetic material.

Some of the results of recent crop improvement efforts that are already helping poor farmers cope with variable weather and early impacts of climate change are described on pages 26–27. The breeding programmes of the CGIAR centres, and their partners (including farmers), will continue to lead the way in developing new, adapted varieties that respond to a changing climate. At the same time, the CCAFS Challenge Program will work to provide guidance on new directions that might improve effectiveness of breeding programmes in light of climate change. One of the early planned activities, for example, is a meta-analysis of past and present multi-location trials to improve understanding of climate sensitivity and tolerance in existing germplasm.

Crops for the future

Drought-tolerant maize for Africa. Drought already reduces global maize yields by as much as 15% annually, and this looks set to worsen with climate change. To counter this, scientists from CIMMYT and the International Institute of Tropical Agriculture (IITA) are working with national partners in sub-Saharan Africa to develop drought-tolerant maize varieties. So far, more than 50 such varieties have been developed, and are being grown on a total of about one million hectares. The success of this work is partly the result of a novel breeding method, in which hundreds of small farmers take part in testing the new varieties.



CIMMYT

New Rice for Africa. Rice is also at risk in Africa as the climate changes. New Rice for Africa, or NERICA, may help. Resulting from the work of the Africa Rice Center and its national partners, NERICA varieties combine the high productivity of Asian rice with the ability of African rice to tolerate harsh growing conditions. Varieties for rainfed uplands are already being grown on 200,000 hectares across 30 African countries. Farmers are particularly interested in early maturing NERICA varieties, which permit more intensive cropping and tend to escape intermittent droughts occurring at critical stages in crop development.

Flood-tolerant rice. With rising sea levels, flooding of coastal farmlands presents a real risk for farmers. Today in Southeast Asia, harvest losses related to flooding have an estimated annual value of US\$1 billion. Rice is the only cereal crop that can withstand any degree of submergence, but most varieties die if fully submerged for more than 3 days. IRRI researchers and collaborators recently identified a rice gene called *Sub1A*, which allows plants to survive completely submerged for up to 2 weeks. The 'waterproofing' trait has been transferred into a popular rice variety in Bangladesh, and the improved version is giving high yields while protecting harvests against flooding.



IRRI

The Rice and Climate Change Consortium. Capitalizing on successful results in developing rice tolerant to submergence and soil salinity (another condition expected to worsen as a result of climate change), IRRI has established a research consortium that is addressing the impact of climate change on rice production in all its complexity. Working from the local to global scales, the consortium relies on crop improvement, with the aid of molecular techniques, while also examining the impact of climate change on ecosystem resilience, pest dynamics and other factors.

IITA



Building on inherent drought tolerance.

Among the world's most naturally hardy food crops are barley, cassava, millet and sorghum, which are widely grown in dry climates. These and other naturally tolerant crops contain a wealth of useful genes for plant breeders. Researchers at ICARDA, for example, are developing varieties of barley that mature earlier, and thus escape drought. Meanwhile in Africa, mechanisms behind the drought tolerance of cassava are being investigated by IITA and the Generation Challenge Programme. And researchers at ICRISAT have isolated genes for the so-called 'stay-green' trait in millet and sorghum.

Drought-tolerant beans. Researchers at CIAT have succeeded in breeding drought-tolerant common beans after nearly a quarter century of research. The new beans yield 600–750 kilograms per hectare under severe drought, roughly double the maximum yield that Latin American farmers get from commercial varieties under the same conditions.



CIAT

Reducing vulnerability of farming systems in the face of climate change demands a turn-around in soil management

Sustainable soil management

Even without climate change, deteriorating soils are one of the main challenges to future agriculture. For example, in recent years some 320 million hectares, or 25%, of the already fragile African drylands have been degraded to an extent known as 'desertification'. This is largely a result of unsustainable practices such as over-grazing, over-cultivation and deforestation, which mines soils of their nutrients without adequate replenishment. In other words, we are running down this critical ecosystem service just when we can least afford to.

Reducing vulnerability of farming systems in the face of climate change demands a turn-around in soil management. We know a great deal about sustainable soil management (see page 29), but we now need a concerted effort to overcome the obstacles that have prevented more widespread uptake of these methods. Helping farmers appreciate the true value of their soils will be key, through participatory

research and learning. Local land rights will need to be addressed, and policy, as always, will need to be supportive. There is also a role for financial incentives, particularly in light of the mitigation bonus that good soil management practices offer.

Soil organic matter is the critical factor. Increasing organic matter content improves soil fertility, nutrient supply, soil structure, water-holding capacity, and a host of other vital soil functions. Ways to do this include adding compost, crop residues, animal manure, and chipped wood, hedgerow intercropping (alley farming), and growing cover crops such as legumes. And, in perhaps the best win-win opportunity for agriculture, more organic matter in the soil means less carbon dioxide in the atmosphere.



A conservation agriculture trial clearly demonstrates the benefits – farmers' traditional soil management practices on the right. CIMMYT.

Technologies to improve soils

Conservation agriculture. Conservation agriculture is based on minimal soil disturbance (reduced or no tillage), combined with organic matter retention (returning crop residues to the soil) and diverse crop rotations. As well as reducing erosion and improving soil structure and soil–water dynamics, this approach also saves on labour, time, fuel and machinery wear. The combination of reduced soil disturbance and increased retention of crop residues also results in increased carbon storage (sequestration). A good example of the effectiveness of conservation agriculture is the rapid spread of ‘zero tillage’ technology in South Asia’s rice–wheat systems. Promoted by a regional consortium with assistance from CIMMYT and IRRI, the technology has been rapidly taken up so that close to half a million farmers in India, Pakistan and other countries of the region now apply this technology on more than 3.2 million hectares, with economic benefits so far estimated at US\$147 million. The Quesungual slash and mulch system provides another example. Developed under a CPWF project led by CIAT, this alternative to non-sustainable slash and burn is proving a success with resource-poor farmers in Honduras, Nicaragua and Colombia. Meanwhile, ICARDA is helping to test, validate and promote conservation agriculture practices in Syria, Iraq and Central Asia.



IRRI

Eco-farming. Combining market orientation with soil rehabilitation, ICRISAT has developed a dryland farming system called the ‘Sahelian eco-farm’, which can multiply farmers’ net income by a factor of six. Drought-tolerant, nitrogen-fixing trees such as *Acacia* species are planted to rebuild the soil, and high-value fruit trees, vegetables and herbal crops are intersown in the field. The leaf litter as well as decaying roots add organic matter to the soil and also reduce wind erosion and increase water infiltration. Small amounts of fertilizer complement the organic matter, and crop yields are boosted substantially.



ICRISAT

Micro-dosing. Applying normal doses of fertilizer is too expensive for most farmers in the Sahel. The use of organic matter, in the form of livestock manure and crop residues, is effective, but supplies of these materials are often limited. A more economical alternative, developed by ICRISAT, is to apply small quantities of inorganic fertilizers in the hole where seed is sown, a practice called ‘micro-dosing’. Practiced by thousands of farmers in Burkina Faso, Mali, Niger and Zimbabwe, micro-dosing helps crops mature more rapidly, yield 50–100% more grain, and escape the worst effects of drought.

Managing changing pests and diseases

Keeping up with changes in pests and diseases of crops and livestock will be another significant challenge as the climate changes. Temperature, humidity, rainfall and other weather parameters influence pest and disease spread through different mechanisms. Higher temperatures speed up the lifecycle of some insect pests, for example, so that pest populations grow faster. Similar impacts on disease vector insects will affect the spread of some diseases. And outbreaks of many fungal diseases, such as potato late blight and ascochyta blight of chickpea, are directly related to climatic conditions.

Where these mechanisms and responses are understood, they can be used in computer models to predict pest and disease movements. Potato late blight models, for example, are being developed for tropical regions, while models for predicting changes to potato pests are also coming into use (see page

Anticipating pest and disease outbreaks, and integrated pest and disease management where outbreaks occur, are the fundamentals

31). In Africa, a model for tsetse fly and the trypanosomiasis it carries is being developed (see page 31). Monitoring actual pest and disease movements will also be important, and will add to knowledge on real-life impacts of climate.

Anticipating pest and disease outbreaks, and integrated pest and disease management (IPDM) where outbreaks occur, are the fundamentals behind managing changing pests and diseases into the future. Participatory learning is implicit in IPDM, so that farmers come to understand the relationships between crops, pests and diseases, and climate. With this knowledge they can adapt their own systems and build resilience.



*Keeping up with pests and diseases will be a challenge as the climate changes.
Neil Palmer/CIAT.*

Managing pests and diseases of the future

Modelling late blight. CIP researchers and collaborators are working on improving a late blight simulation model that was developed at Cornell University in the 1980s. The model was used extensively in the USA, but was found deficient when applied to epidemics in Ecuador or Peru. Researchers are now modifying the model to make it accurate in diverse agro-ecological environments. The model will be used to estimate changes in disease severity under different climate scenarios, and to test disease management options prior to validating them in the field.

Modelling potato pests. CIP scientists have also developed models to predict changes in range and biology of several insect pests of potatoes as the temperature rises. With a 2–3°C rise, the highly damaging potato tuber moth, for example, is expected to extend its range about 400–800 km north in the northern hemisphere, and also 100 metres in altitude in tropical mountainous regions. Moth activity will also increase, and lifecycle time will shorten.

Simulating tsetse-transmitted trypanosomiasis in Kenya. An ILRI project aims to build and test a predictive model that defines the relationships between climate change, land use and cover change, social systems and ecological disturbance on the distribution of tsetse flies and African trypanosomiasis or sleeping sickness across Kenya. The information produced will directly affect on-going tsetse control programmes and make a substantial contribution to understanding broader patterns of human–environment impacts, disease emergence, transmission, prevention and control, and future risk.

Ascochyta blight. Ascochyta blight is the world's most important chickpea disease. Caused by the fungus *Ascochyta rabiei*, favourable conditions for its spread are wet weather and mild temperatures. Traditional landrace varieties are highly susceptible, but ICARDA breeders have developed a range of elite lines that are moderately to highly resistant. These form a major component of a low-cost IPDM package to control the disease, which also includes use of high-quality seed pretreated with fungicide, crop rotation (to avoid fields with infected debris), delayed sowing (to ensure that humidity is low when plants are most vulnerable), weed control, more widely spaced plants (therefore less humidity within the plant canopy), and chemical fungicides used judiciously. However, climate change may mean that breeders have to return to the laboratory. Current improved varieties are only resistant in the early growth stages, which coincide with wet and mild weather when blight might occur. In the dryland regions where chickpea is grown, rain has normally been highly unlikely later in the season, but this could now change, requiring responses in the IPDM package.



ICARDA

Modelling rice diseases virulence in East Africa. Not only the geographical distribution of diseases, but also virulence is expected to change under a changing environment. Scientists at the Africa Rice Center are studying the effect of climate change on the virulence of blast and bacterial leaf blight in Rwanda, Uganda and Tanzania.

Livestock systems for the future

As the climate changes, there will inevitably be impacts on livestock and livestock-based systems. At the same time, as the global demand for meat and other animal products increases, animal numbers are growing rapidly, with accompanying impacts on ecosystems such as rangelands and pasturelands, and on demand for water. The solution is to manage growth of the livestock sector sustainably, through adaptive strategies that simultaneously address the climate challenge to livestock-based systems and the livestock pressure challenge to the environment.



Livestock keepers will need to build adaptive strategies. Stevie Mann/ILRI.

The solution is adaptive strategies that simultaneously address the climate challenge to livestock-based systems and the livestock pressure challenge to the environment

These adaptive strategies will include diverse options from which livestock keepers can select. Some options address sustainable management of the natural resources on which systems depend; others are market-oriented, aiming to improve market access and increase incomes. Examples include using livestock species and breeds best suited to future climates, and adapting flock composition. Managing feed supplies will be critical, and will depend on a range of approaches, from developing alternative feeds that are not dependent on crops, to planting appropriate species under rangeland rehabilitation programmes. Rangelands are some of the most vulnerable ecosystems – they comprise vast arid and semi-arid regions across some of the world’s poorest countries, and have been significantly degraded over recent decades. Their rehabilitation – which will be critical in order to meet future challenges including climate change – requires strategies that address effective water management alongside multiple uses including animal production, wildlife conservation and carbon sequestration. Payments for environmental services will be part of successful strategies.

Mobility will remain an important coping strategy for poor pastoralists as the climate changes, and inevitably there will be more permanent migration over time. Migration is often accompanied by conflict, and also tends to bring new and sometimes inappropriate land management technologies and methods that exacerbate an already volatile situation. Systematic conflict mitigation measures need to be put in place, and supported by robust land use and access policies and planning.

Innovations for livestock systems

Local breeds and participatory breeding.

Local breeds of livestock are often tolerant to temperature extremes and can remain productive even on degraded rangeland. They are therefore likely to cope better with climate change than exotic breeds. Breeding programmes are therefore focusing on improving specific traits (e.g. milk yield, growth rate) in local breeds. To facilitate this, ILRI, ICARDA and their partners have developed a new approach called community-based participatory breeding. First, the community identifies specific breeding objectives. The entire community flock is then used as a single breeding pool to improve the target traits. Participatory breeding projects have been implemented in Ethiopia, Mexico, Kyrgyzstan and Tajikistan.



Dorine Adhoch/ILRI

Fodder banks. Developed by ILRI and partners, fodder banks offer a feed management option particularly useful through scarce periods due to drought, for example. The 'bank' consists of a small area enclosed by a fence and planted with legumes such as *Stylosanthes*. A farmer uses this 'bank' as she would a larder or pantry, drawing on it when fresh food (green grass) is not available for her animals.

ICRISAT



Replanting rangelands. As a result of overgrazing, cutting of shrubs and trees for fuel and removal of vegetation, valuable rangeland species are being replaced by less valuable species unpalatable to livestock. Researchers are looking for suitable replacement species that can provide fodder as well as help to rehabilitate degraded rangelands. ICARDA has successfully introduced several shrubs and drought-tolerant species, such as *Atriplex* and *Acacia* species and spineless cactus.

Diversification of dairy products. Diversification of products can help increase the resilience of production systems. In some countries like Syria, the number of intensive dairy production systems has increased in recent years. Farmers process their own milk, mainly into yoghurt and local cheese, rather than selling it as fresh milk at a low price. Improving quality, shelf-life and marketability of these dairy products is critical for the farmers to respond to market standards on food safety and hygiene. ICARDA is working with these dairy farmers to help them improve both their processing and marketing skills.

Sustainable fisheries and aquaculture

Fishing and aquaculture provide food and livelihoods for many millions of resource-poor people, and may become even more important to global food security as the climate changes and other sources of food become less reliable. Both are vulnerable, however, to a range of environmental pressures including climate change. Many capture fisheries worldwide have declined sharply in recent decades or have already collapsed from overfishing, while pollution, mismanagement of freshwater, and coastal development also pose serious threats. Adaptive strategies must address these problems, as well as those that a changing climate will add.

Aquaculture, on the contrary, is growing in many parts of the world, and offers some good opportunities to adapt to climate change. Farming fish provides an easily managed and predictable source of food. By focusing on herbivorous species, aquaculture can provide food with a low carbon footprint. Fish are highly efficient at converting grain to protein – cattle require around 7 kg of grain to produce 1 kg gain in live weight but herbivorous fish, such as tilapia or carp, need less than 2 kg. And ironically, it requires less water to grow fish

Fishing and aquaculture may become even more important to global food security as the climate changes and other sources of food become less reliable

than meat as the water is mostly recycled and not consumed. Climate change could open up new opportunities for aquaculture as the sea encroaches on coastal lands, as more dams and impoundments are constructed in river basins to buffer changing rainfall patterns, and as urban waste demands more innovative disposal. Small-scale aquaculture also holds promise as an option for diversifying livelihoods, as demonstrated in Malawi (see page 35).

Aquaculture may go some way to compensate for the decline in capture fisheries in the coming years, but that certainly does not mean capture fisheries – and the aquatic ecosystems on which they depend – should be ignored. Small-scale capture fisheries provide food and livelihoods for some 150 million people; and the world's seas and rivers provide a host of environmental services beyond food production, which means their sustainable management should be high on any environmental agenda for the future.



Fishing and aquaculture provide food and livelihoods for many people. Edward Allison/WorldFish.

Fisheries and aquaculture

Learning from communities – I. Through the CPWF, WorldFish is studying collective approaches to fish culture on seasonal floodplains in Bangladesh, Cambodia, China, Mali and Vietnam. The research seeks to understand how communities exposed to dramatic environmental variation adapt their livelihood strategies and design institutions that govern access to areas that are dry land in some seasons and under water in others. Developing locally appropriate fish-culture technologies and understanding the conditions for collective action to support them are first steps in developing adaptation strategies on these and other floodplains.

Learning from communities – II.

WorldFish scientists have developed a participatory diagnostic and adaptive management framework for small-scale fisheries. This is being used to examine how fisherfolk are vulnerable to the compounding effects of multiple stresses in fishery systems, as well as exogenous economic, social and environmental drivers, and how they cope with them. The framework is currently being applied in two contexts: in tsunami-affected fishing communities in



Dedi Supriadi/Adhuri/WorldFish

the Solomon Islands, where fisheries are already under a range of stresses, including overfishing, and face new threats such as climate impacts on coral reefs; and in the Niger River basin, which has a long history of vulnerability to drought and reduced river flow.

Diversifying livelihoods with aquaculture. WorldFish is working with Malawi's Fisheries Department to help farmers diversify into aquaculture. Farmers set aside a small amount of their land for fish farming. Fish are fed maize bran and household leftovers, while manure from goats, chicken and rabbits helps fertilize the ponds. In addition to using water from the ponds to irrigate maize fields (the traditional crop) and vegetables such as cabbage and tomatoes in their garden during the dry season, farmers grow cash crops like bananas and guava around the banks of their ponds. They use the water from the ponds directly or utilize the effect of seepage to provide moisture for their crops. Pond sediments make great fertilizers. Farmers produce some 1,500 kilograms of fish per hectare per year, providing high-quality protein for their families. The net farm income of adopters exceeds that of non-adopters by 60%, and their farms are also some 18% more productive than traditional ones during times of drought, increasing farm resilience and food security.

Salt-tolerant tilapia. Tilapia is one of the most widely farmed fish species in the world. Research has shown strain differences in tolerance to saline environments, and WorldFish scientists have begun to exploit this capacity to develop salt-tolerant strains.

The adaptation needs of forest communities today, and the mitigation needs of global society today and in the future, are inseparable

Forests and forest communities

The forests of the world need to be safeguarded as the climate changes. Their indispensable role in reducing the vulnerability of global society to climate change demands they be preserved and managed sustainably into the future. This, and the vulnerability of communities who make their livelihoods from forests, means that adaptation strategies for forests are essential.

An estimated 1.6 billion people have livelihoods that are intricately linked with these ecosystems and their unique biodiversity. Forests provide food and nutritional supplements, fuel, timber and medicinal products – to forest dwellers, but also outside forests. Managing these demands sustainably can be done (see page 37).

Reducing pressure on forest resources will be at the heart of both adaptation and mitigation strategies for forests. Changes to

the valuing of forest resources, and the inclusion of forest ecosystem services in new forest valuation systems, will be critical. Biodiversity conservation and use must be integral to new forest management strategies. The drivers of deforestation need to be addressed, along with property rights and control of migration into forest margin areas.

The adaptation needs of forest communities today, and the mitigation needs of global society today and in the future, are largely inseparable. Successful strategies for forest management into the future will therefore encompass both adaptation and mitigation measures.



Fundamental changes are needed to the way we manage forests. CIFOR.

Adaptation for forests

CIFOR



Forests of the Congo Basin. A large adaptation project led by CIFOR is undertaking research in the forests of the Congo Basin. It aims to develop adaptation strategies in the Congo Basin forests without jeopardizing the integrity of these forests to ensure the continuous provisioning of ecosystem goods and services vital for household livelihoods, national development and economic growth of the region.

Linking climate change adaptation and mitigation through agroforestry. Agroforestry systems are attractive land management practices that span both adaptation and mitigation objectives. Tree-based systems have some obvious advantages for maintaining production during wetter and drier years: trees are less susceptible than annual crops to weather variability and extremes like droughts or floods. Tree-based systems also deliver products such as fruits, fodder, fuel wood and timber. At the same time, they store significant amounts of carbon, in trees and soil. By adding trees to their systems, farmers are actively adapting to weather variability and uncertainty, and contributing to mitigation of future climate change

Anne Moorhead/Green Ink



Complex smallholder forest gardens. One of the most promising agricultural systems in the face of climate change is the complex forest garden. This approach, promoted by the World Agroforestry Centre, combines a wide range of crops, trees and animals in a flexible production system that offers economic as well as climate resilience. These systems make efficient and effective use of water and nutrients, and are adaptable as species viability changes with changes in the climate. Carbon storage in forest gardens is similar to levels in some natural forests, so they effectively address both mitigation and adaptation.

The CCAFS Challenge Program will place livelihoods at the heart of the adaptation and mitigation strategies it develops

Livelihoods in transition

The adaptation options discussed above, and many others, will comprise the portfolios from which farming, fishing and forest communities and other natural resource managers can select to build resilient, adapted livelihoods. They will need help with this on many levels, but the choices must be made by the people whose livelihoods are in transition. There will be trade-offs at the local level that only the communities themselves can understand and decide upon; and any changes must make sense to communities in the short term, as well as promising livelihood options and natural resources that will still be available and useful to their children.

Participatory research and learning will be key in increasing knowledge and building capacity for such decision making. New approaches to engagement and communications will play an important role. Page 39 describes

some steps already being taken in building adaptive capacity.

The CCAFS Challenge Program will place livelihoods at the heart of the adaptation and mitigation strategies it develops. Building on the component adaptation technologies developed by the CGIAR centres and partners, CCAFS will design and assess integrated portfolios of adaptation and mitigation options that focus on livelihoods and food security at household and higher levels. In between the paradigms of 'planned' adaptation to a known change and the 'risk reduction by diversity' approach to increased uncertainty, it will explore 'planned diversity' and 'diversity of plans', as elements of a higher order risk management strategy.



Choices must be made by those whose livelihoods are in transition. World Agroforestry Centre.

Building adaptive capacity

Building adaptive capacity in Zambia and Zimbabwe.

ICRISAT is involved with a project that seeks to improve incentives and opportunities for households to cope with and adapt to the increasing vagaries of climate through improved crop production practices. The adoption of these practices will be stimulated by linking their dissemination with complementary investments in climate forecasting, and building linkages to other projects that have either a humanitarian relief focus or are involved in the development of input

and product markets. Key interventions include: (1) building local institutions and demand-led rural service provision; (2) strategies and decision-support tools for managing smallholder assets, including livestock; and (3) participatory development of new technologies for natural resource use under variable rainfall.



World Agroforestry Centre

Rehabilitating livelihoods following natural disasters. WorldFish has developed a framework for rehabilitating coastal livelihoods and communities following disasters. Building on lessons learned following the tsunami off Aceh in 2004 and an earthquake off the Solomon Islands in 2007, the rehabilitation framework stresses diversifying coastal livelihoods instead of just restoring practices of the past. It seeks to address the root causes of vulnerability and so build resilience in coastal communities that will enable them to cope with future threats and seize future opportunities.

A systems approach in the Andes. A CIP project called ALTAGRO is working in the high altitude regions of Peru and Bolivia, one of the poorest areas in the world and characterized by high weather variability and uncertainty. The project takes a systems approach that embraces both farming and non-farming activities. It represents a model for rural development based on a comprehensive view of sustainable agriculture, which encompasses the economic, biophysical, socio-cultural and environmental aspects of market-oriented development. Capacity building includes work with school children to introduce science-based concepts on climate change and variability to future farmers.

Mitigation – pro-poor, sustainable and essential

There are many changes that need to be made in the coming years, at all levels of society, to reduce greenhouse gas emissions. Agriculture, while not the main culprit in climate change, does contribute significant amounts of greenhouse gases that cannot now be ignored in mitigation efforts. But more than this, changes to the management of tropical lands offer additional mitigation opportunities through their capacity to store carbon. The very good news is that many of these mitigation opportunities also enhance adaptive capacity and sustainability of systems, and contribute to development generally. On the other hand, there are significant challenges to overcome, in linking small-scale resource management to carbon markets for example, before these opportunities can be fully exploited. These challenges must now be addressed as a matter of urgency, before these largely win-win opportunities are lost.

Today agriculture contributes about 14% of annual greenhouse gas emissions, and forestry another 17%. Irrigated rice systems produce significant amounts of methane, while nitrous oxide is a by-product of soil management systems that add nitrogen fertilizers. Burning of vegetation – trees and crop residues, for example – is a very direct path to raising atmospheric carbon dioxide levels. Livestock systems also contribute – animals produce methane, while manure is another source of nitrous oxide. Yet all of these offending practices can be changed, with the right support and incentives (see pages 42–43).

The management of soils and trees to capitalize on their carbon storage potential (and thus reduce carbon in the atmosphere) is the main bonus that agriculture has to offer to the

The very good news is that many mitigation opportunities also enhance adaptive capacity and sustainability of systems, and contribute to development generally

world's mitigation efforts. There are different ways to boost the carbon content of different agricultural systems. No-till farming, mulching and cover cropping are all low-tech ways to improve the carbon content of cultivated soils. Careful fertilizer management, balancing use of organic manures and inorganic fertilizers, also enhances carbon sequestration. Where soils are low in carbon, such as the degraded soils of over-grazed rangelands, there is great potential for carbon sequestration through extensive planting programmes. Agroforestry has multiple benefits besides its carbon-capturing role – selected tree species provide animal fodder, fruits, timber and medicines, for example, as well as contributing to soil health. Mangrove conservation similarly contributes to coastal protection, sustainable ecosystems and livelihoods at the same time as mitigating climate change. Indeed, the win-win nature of many of these practices should hasten their adoption. At the same time, the value of carbon storage within these systems for global society should be demonstrated by incentives to resource managers, to tip the balance firmly in favour of such practices.

Linking these activities to carbon markets is a way to do this, but is no simple task. One of the challenges is accurately measuring greenhouse gas emissions and carbon content of soils and vegetation, in order to verify changes due to changed practices, and so determine payments. Advances are being made, and low-cost solutions found (see page 43). The next stage is to develop a framework that allows the inclusion of small-scale carbon sequestration projects in global carbon markets.



Sustainable forests are an important part of the solution. CIFOR.

Biofuels present a complex subject but one that needs to be unravelled so that they can take their place in a future, fossil-fuel-free world. On the one hand, they are renewable, potentially sustainable, and produce less carbon emissions than fossil fuels. They can be produced by any country and could provide rural communities with new sources of income and employment; indeed, many tropical countries may find that they have a comparative advantage in producing and exporting biofuels, and several countries have already embarked on pilot projects. On the other hand, production systems are over-stressed and growing crops for biofuels will add to this pressure on the land and other resources, particularly water. Production of these crops may compete with that of food and feed crops, with obvious negative consequences that will hurt the

poor most. And the production of biofuels currently relies to some extent on fossil fuels, so that there is not necessarily a clear gain in terms of reducing carbon emissions. Work to clarify the issues and advance pro-poor biofuel development is described on page 43.

The final research theme of the CCAFS Challenge Program will explore opportunities for mitigation synergies with adaptation strategies, to benefit small farming, fishing and forest communities. It will quantify improved practices in terms of carbon sequestration, as well as analysing traditional versus improved practices to assess trade-offs. It will also investigate payment schemes for environmental services, and develop a greenhouse gas measurement and monitoring system for use at the farm and landscape level.

Mitigation opportunities



Reducing methane emissions from rice systems. Irrigated systems provide much of the world's food, but also produce greenhouse gases from chemical reactions between the water, fertilizers, soil bacteria and the plants themselves. Rice fields are often extensively flooded and produce significant amounts of methane. However, some simple changes in water regime can reduce emissions without yield losses. IRRI has demonstrated this in field experiments in the Philippines and

beyond. Alternative wetting and drying replaced continuous flooding of rice fields, and farmers were able to see that yield was not reduced, and that water was used much more efficiently.

Reducing nitrous oxide emissions from soils. Nitrous oxide is produced by microbial action on nitrogen compounds which are usually added as fertilizer. Fertilizers are important for improving yields, but additions are generally highly inefficient, leading to emissions. The key is to increase nitrogen use efficiency by the plants, and there are various ways to do that. Fertilizer best management practices are based on the principle of 'right source, at the right rate, at the right time, and with the right placement'. A tool to help with this has been developed by CIMMYT researchers, which uses hand-held infrared sensors that measure how much nitrogen fertilizer farmers need to apply in their maize and wheat crops. Meanwhile, CIAT scientists are studying a chemical released from the roots of a forage grass which triggers a process called biological nitrification inhibition (BNI). This process slows the conversion of nitrogen compounds into nitrous oxide. If scientists succeed in isolating the genes responsible for BNI and can introduce it into other crops, the results could be truly revolutionary. Researchers at CIMMYT are seeking genes for BNI in wild plants related to wheat.

Reducing deforestation. Deforestation is a hugely complex issue, and reducing and reversing it requires action at many different levels, from global policy to local empowerment and diverse technologies that promote sustainable forest management. CIFOR is working across these levels to come up with solutions. Informing the policy debate, so that post-2012 agreements include REDD schemes that are equitable and provide benefits to communities, is a major area of focus. Providing information and tools that stakeholders need to bring about change is also high on CIFOR's agenda. For example, certification schemes that guarantee forest products are from sustainably managed forests are already helping small forest managers and communities identify and protect biodiversity across millions of hectares of tropical forests.

Lowering greenhouse gas emissions from livestock systems. There are many ways to reduce emissions from livestock systems, according to ILRI. Feeding better quality diets to ruminants reduces methane emissions, and can be facilitated with improved fodder technologies such as improved pasture species and use of legumes. Manipulation of rumen microflora and use of feed additives are also effective. Switching livestock species or breeds allows replacement of many low-producing animals with fewer but better fed animals, thus reducing total emissions while maintaining the supply of livestock products.

Managing soils for carbon sequestration. Soil carbon sequestration involves adding as much carbon as possible to the soil, and offers the biggest win–win mitigation–adaptation opportunity from farming systems. Conservation agriculture is one very effective approach; agroforestry is another. For example, the Quesungual slash and mulch system, developed by CIAT under the CPWF, is improving soils and livelihoods in South America. Annual crops and pastures are grown alongside replanted native forest vegetation. Management involves no burning and zero tillage. More than 6,000 farmers who have adopted the system during the last 10 years have more than doubled crop yields.

Mangrove conservation. Mangroves not only provide critical ecosystem services (including the provision of a nursery area for many juvenile fish, trapping sediments and preventing coastal erosion) but are also important sinks for carbon dioxide. Through a WorldFish project, Solomon Island researchers and government officers are being trained on the issues and opportunities associated with carbon credit trades, and the quantification of mangroves' contribution to carbon sequestration.

Methods for measuring greenhouse gases. Researchers at the World Agroforestry Centre have devised and are applying a new technique in Eastern Africa that assesses soil conditions, including carbon stocks, with a high degree of accuracy. Involving the use of satellite imagery and infrared spectroscopy, the technique is much cheaper than on-the-ground verification. Using this technology, a team of scientists in Kenya is providing government officials with environmental data covering an area of 19,000 square kilometres to guide a comprehensive effort to rehabilitate degraded agricultural land in the watersheds that feed Lake Victoria.



World Agroforestry Centre

Pro-poor biofuels. ICRISAT is assembling the elements of a biofuels initiative designed specifically to benefit the poor in regions facing the threat of desertification. One of the initiative's components consists of new varieties of high-sugar sorghum, which can be grown for ethanol production. Since sorghum produces grain and fodder as well, the new varieties should help address the food–feed–fuel dilemma. In addition, sweet sorghum is well adapted to drought-prone environments, requiring only a seventh of the amount of water required for sugarcane, another biofuel crop.



The future of agriculture depends on the decisions we make now. Neil Palmer/CIAT

The CCAFS Challenge Program and the CGIAR centres are committed to pushing the boundaries of science in the search for ways to stay ahead of climate change

Conclusion



Climate change promises serious negative impacts on agricultural systems. These same systems and the natural resources that support them are already under severe strain from over-exploitation, the current climate, and multiple other stresses. Many of the world's most vulnerable people depend directly on these systems for their food and livelihoods; and many countries' economies are also highly dependent on them. Agriculture is also adding to the climate change problem. This is the story so far.

We are at a crossroads in the development of our planet. The decisions we make now, for agriculture and natural resources as well as for other sectors, may prove to be the most important decisions humankind ever collectively makes. The two groups that stand to lose the most if the wrong decisions are made – the world's poor, and future generations – are, ironically, the same groups who are least responsible for climate change and who have the least voice in the debate. Food security is one of the basic human rights that is in jeopardy. Today, an estimated one billion people – more than one person in six – do not enjoy that right; without significant

changes to agriculture and other natural resource-based systems, hunger and poverty will be perpetuated long into the future, and affect many more.

We know what to do to raise our chances of a better future. Building on several decades of research by the CGIAR centres and their partners, we know how to make agricultural and other natural resource-based systems more productive and more sustainable. Even without climate change, we have a moral imperative to turn this knowledge into action. Climate change adds urgency to the situation, but it also provides an opportunity. The products of agricultural research are ready to be implemented in adaptation and mitigation strategies that will help people build successful livelihoods despite changing conditions.

As the future climate unfolds, more will be needed. Agriculture – and agricultural research – face a race against time. Over the coming years, the CCAFS Challenge Program and the CGIAR centres are committed to pushing the boundaries of science in the search for ways to stay ahead of climate change. The future of agriculture may depend on these efforts.

The following are gratefully acknowledged for their contribution to this publication:

Wale Adekunle, Sub-Saharan Africa Challenge Program

Eddie Allison, WorldFish Center

Howarth Bouis, HarvestPlus Challenge Program

Peter Cooper, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

Andy Jarvis, International Center for Tropical Agriculture (CIAT) and Bioversity International

Markku Kanninen, Center for International Forestry Research (CIFOR)

Mohammed Karrou, International Center for Agricultural Research in the Dry Areas (ICARDA)

Paul Kiepe, Africa Rice Center

Tuppy McIntosh, Challenge Program on Water and Food (CPWF)

Gerald Nelson, International Food Policy Research Institute (IFPRI)

Henry Neufeldt, World Agroforestry Centre (ICRAF)

Antonia Okono, Generation Challenge Programme

Rodomiro Ortiz, International Maize and Wheat Improvement Center (CIMMYT)

Roberto Quiroz, International Potato Center (CIP)

Thomas Rosswall, Challenge Program on Climate Change, Agriculture and Food Security (CCAFS)

Vladimir Smakhtin, International Water Management Institute (IWMI)

Kai Sonder, International Institute of Tropical Agriculture (IITA)

Philip Thornton, International Livestock Research Institute (ILRI)

Reiner Wassmann, International Rice Research Institute (IRRI)

Many millions of people in developing countries face a very real and direct threat to their food security and livelihoods as climate change unfolds. Yet we have at our disposal a wealth of knowledge that, if turned into action, would allow these same people to build resilient livelihoods and prosper in spite of variable and uncertain weather. This publication describes the work of the centres of the Consultative Group on International Agricultural Research (CGIAR) and their partners that comprises this bank of knowledge, and urges decision makers to take the steps needed to put this research into action. It also presents a new initiative – the Challenge Program on Climate Change, Agriculture and Food Security – which combines the expertise of the CGIAR with that of the Earth System Science Partnership, and which will open up new frontiers in the search for solutions for agriculture as the climate changes.

