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Climate Change Challenges and Adaptations at Farm-level

Case Studies from Asia and Africa

EDITED BY NAVEEN PRAKASH SINGH, CYNTHIA BANTILAN, KATTARKANDI BYJESH AND SWAMIKANNU NEDUMARAN

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CABI Climate Change Series

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Foreword

Climate change is occurring and its effects are already being felt. Climate change will have an impact on several sectors including agriculture, fisheries and water on which the world's population depends for their sustenance. The full impact is imminent, irrespective of the geographical distribution, and is going to be severe. The urgent need is to address the question of who are highly vulnerable and are immediately at risk, as the critically affected population requires attention and targeting to improve their capacity to overcome the associated risks. Until recently, most scientific assessments on climate change impacts, adaptation and resilience focused on the macro or regional level, with concentration on agriculture production, food supply, natural resource sustainability especially in Asia and Africa, and with less consideration at the community and farm household level.

This book is a compendium of studies on climate change challenges and adaptations at the farm level, capturing research carried out across the continents of Asia and Africa. This was spearheaded under the auspices of ICRISAT, along with partners and like-minded organizations, globally contributing to the research paradigm of improving resilience among the farming communities in the semi-arid tropics region. It primarily features the key findings of a pioneering initiative supported by the Asian Development Bank on `Vulnerability to Climate Change: Adaptation Strategies and Layers of Resilience', encompassing vulnerable target domains in Asia. It also captures key findings from equally important initiatives in sub-Saharan Africa (Ghana and Niger in West and Central Africa) and Kenya in East and Southern Africa.

The book reiterates that climate change adaptation and mitigation are a practical necessity, as well as a moral imperative at the grass-roots level: farm, household and community – as they significantly affect agriculture. The people who are bearing the brunt of the effects of climate change are those who can least afford to do so. The identification of adaptation strategies and layers of resilience at the grass-roots level is viewed as an essential step in addressing vulnerability to climate change (water scarcity, drought, desertification, land degradation and further marginalization of rain-fed areas). Research was envisioned to provide science-based solutions and approaches to adapt agricultural systems to climate change for the benefit of the rural poor and the most vulnerable farmers in the semi-arid regions of Asia and Africa. Moreover, climate experts have been able to identify the causal factors influencing changes in productivity – attributing them to both climate change and instability – and used this information to diagnose what needs to be done to manage or reverse the alarming trends observed in recent decades, which may render planet earth uninhabitable in the long-term. The diagnosis will enable the prioritization of sectors most at risk and the development of equitable adaptation and mitigation strategies as an integral part of agricultural development programmes in more vulnerable regions. The initiatives have generated a useful road map and a policy matrix to inform policy decisions on critical issues affecting the future of agriculture and livelihoods in the rain-fed semi-arid tropical region. Hence, the micro-level research findings are an essential tool that guides policy making on all issues ranging from agriculture, health, industry, pollution control, global warming and sustainability issues in the face of climate change, fluctuations and extreme events.

The vital role that institutions such as ICRISAT plays, is in guiding research partners and policy makers towards integrating agricultural science with the economic, social and environmental dimensions of development, taking into account farm-household level evidence-based insights. ICRISAT declared a ‘Hypothesis of Hope’ on climate change and vulnerability by stating, `how farming systems cope with *current* rainfall variation is likely to yield important clues for adapting to *future* climate change’. ICRISAT believes that the gap between the farmers’ yield and achievable potential yield can be effectively bridged to ensure food production and sustainable livelihoods for the farmers. The approach includes integrating the adoption of climate-resilient crops and best practice soil, water and nutrient management strategies, along with supporting policies and institutions. Emerging science tools such as remote sensing, modeling and conventional natural resource management technologies will have to be harnessed, together with social and policy interventions to achieve the desired results.

A grass-roots approach is vital where the community is an active partner in learning, finding solutions and jointly adapting best practices that work for them. People will do what they finally decide is good for them. The technology, tools and methods we develop for the farmers have to be ultimately accepted and owned by them however informal or crude their evaluation may be. From the scientific research side, a grass-roots perspective and understanding of the context in which farmers live and manage their livelihoods is equally important. Keen observation and documentation of farm-household behaviour and responses in the villages as well as examining issues and variance of farmer realities enhanced the objectivity of results and priorities. Greater effort was spent on examining what is happening, listening and learning from the women and men, young people, families and communities in the marginalized and most vulnerable sector.

Recognizing the importance of capturing grass-roots level reality, responses and coping mechanisms, ICRISAT streamlined its research agenda on the semi-arid tropics and other vulnerable areas to draw attention to grass-roots adaptation to climate change and vulnerability. Our partners, the participating countries, were first to recognize that research findings must find their way to policy and development protocols. There is a need for champions, or strong advocates, among individuals and collectives, to break the institutional structures and processes that may be acting as barriers to change. The motto, ‘Act Now, Act Together and Act Differently’, draws from the synthesis of grass-roots level experience with an inclusive and sustainable orientation. Identifying the causes and what needs to be done to mitigate and adapt to climate change is a relatively easier task. The bigger challenge is to make sure that the changes recommended based on research findings are actually accepted, adopted and implemented.

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Preface

In response to increasing concerns on the impact of climate change on the farming and livelihood of smallholder farmers in Asia and Africa, there is a consensus among the international community to focus on research and development activities towards a climate-resilient environment. In the direction of this effort, quantifying the impacts, vulnerability and efforts to streamline the adaptation options, and their efficiency and advocacy at the micro-level, several development agencies, the Consultative Group for International Agricultural Research (CGIAR) through the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) had prioritized their resources and investment in the area of climate change research. Substantial investments are channelled by the national governments and development agencies in Asia and Africa to sustain productivity to conserve natural resources, efficiently adapt farming against climate change and thereby protect livelihood and food security.

This book will definitely serve as a valuable reference for development practitioners, academics, researchers, agricultural scientists, etc. who are interested in the topic of climate change and its consequences. The experiences from the two continents are discussed in detail in this volume. Both quantitative and qualitative approaches adopted in understanding the impacts, adaption options and vulnerability both at crop and household level are highlighted.

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This compendium of studies from Asia and Africa is an outcome of the studies carried out in these regions at the International Crops Research Institute of the Semi-Arid Tropics (ICRISAT) along with project partners. The research was spearheaded by the Research Program on Markets, Institutions and Policies (RP-MIP) at ICRISAT with financial support from the Asian Development Bank. We are indebted to William Dar, Former Director General and other scientific, technical and administrative staff of ICRISAT for their help and cooperation at each and every stage of project execution. We are also thankful to all reviewers who reviewed this manuscript and gave critical comments that helped in improving this book.

1 Climate Change Vulnerability and Adaptation Strategies at Farm-level: A Retrospection

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Abstract

This chapter introduces current and future climatic implication on national, regional and sub-regional agro-socio-economy. It focuses on the growing recognition of the climate change studies that are being considered inevitable. Authors argue that better understanding and assessment of adaptation and/or coping strategies at farm-level are prerequisite in the long-term development planning of the country or the region towards climate resiliency. The arguments were put forward to emphasize the vital link between agriculture, rural livelihoods and climate in the semi-arid tropics for the majority of the population in Asia and Africa. This chapter confines itself to various discourses on the past and present efforts on assessing impacts, adaptation and vulnerability to climate change particularly in the semi-arid tropics of Asia and Africa. It also discusses the global efforts on improving resilience against climatic risks in agricultural sector and also poor smallholder farmers of the semi-arid tropics. The chapter briefly reviews the current state of knowledge related to farmers' strategies and determinants of decision in the choice of adaptation at farm-level. The chapter further discusses the organization of the book and also identifies potential uses of the book and the audience for whom this information is valuable.

1.1 Introduction

> Adaptation is a vital part of a response to the challenge of climate change; it is the only means to reduce the now-unavoidable costs of climate change over the next few decades.
>
> Sir Nicholas Stern, 'The Stern Review' on economics of climate change, October 2006

Climate change is emerging as the biggest threat to livelihood sustainability of our times, posing an imminent danger to human security and the development of human capabilities. Until recently, the centre of attention has been on the actual or potential impact of climatic change and mitigation options. The focus is now shifting to the ways that different socio-economic groups are attempting to cope and adapt to climate variability in particular and climate change in general. International developmental agencies are inclined towards improving their understanding of climate change science, impacts and mitigation of climate change at the global and regional levels (ADB, 2009). This focuses on the growing recognition that, while climate change is inevitable, its effects can be largely extenuated with better understanding of adaptation and undertaking coping strategies.

Global mean temperatures have been rising since the last century mainly owing to greenhouse gas accumulation orchestrated mostly by anthropogenic activities. The main causes are the burning of fossil fuels (coal, oil and gas) to meet the increasing

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energy demand together with intensive agricultural production and deforestation. Along with temperature, the climate itself is perceived to be continuously changing all over the world. Due to its adverse impacts, climate change has always been a matter of great concern to the farming, scientific and developmental communities. Climatic extreme events together with an increase in rates of change in climatic parameters could affect various sectors including water, agriculture, health, tourism, transport, energy and the like. The Human Development Report (2008) states that climate change is one of the greatest challenges humanity faces and/or will be facing, and it is considered the world's most vulnerable population who are immediately at risk. In the future, the climate change associated impacts are imminent with the anticipated vagaries of the weather. According to the Assessment Report 4, AR4 (IPCC, 2007) the projected changes are summarized as follows:

- The surface air temperature increased worldwide and is greater at higher latitudes. Evidence of changes in natural ecosystems is being affected by regional climate changes, particularly temperature increases. Annual average temperature is projected to rise by 0.6–4.1°C by the end of this century.
- There is an observed significant increase in precipitation in eastern parts of North and South America, Northern Europe, and Northern and Central Asia, but reduction in Sahel, the Mediterranean, Southern Africa and parts of South Asia.
- It is likely that there will be an increase in extreme weather conditions, namely heat waves, heavy precipitation, cyclones, and very likely that precipitation will increase in higher latitudes and decrease in most subtropical land regions.
- The water resource sector, owing to changes in rainfall and increased evapotranspiration, will be in crisis in major dry regions in mid-latitude, including the dry tropics. Thereby agriculture will be affected due to limited water availability. Africa and Asia, owing to a large population and low adaptive capacity, are projected to be highly vulnerable to climate change.

The Intergovernmental Panel on Climate Change (IPCC) and various bodies have therefore defined both vulnerability and adaptation for better understanding of the relationships they share with climate change. The IPCC (2001) defines vulnerability as the degree to which the system is susceptible to, or unable to cope with, adverse effects of stresses including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its ability to adapt or adaptive capacity. The Energy and Resources Institute (TERI) states that vulnerability varies across geographical scales and temporal scales, and must be addressed within complex and uncertain conditions, and hence calls for interdisciplinary and multiple expertise (TERI, 2005). Adaptation, on the other hand, is defined by the IPCC (2001) as adjustments in ecological, social or economic systems in response to actual or expected stimuli and their effects or impacts. Hence, adaptation refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change. On similar lines, the Department for International Development (DFID) defines adaptation as reducing the risks posed by climate change to people's lives and livelihoods. Reducing vulnerability by an adaptation and mitigation process requires identification of different potential options that may be selected depending on the local contexts. It has been mentioned that 'A wide array of adaptation options are available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood' in the latest version of the synthesis report (IPCC, 2007). Nature, land, water and associated ecosystems are being degraded rapidly, undermining food security and rural livelihoods. The expected realm of environmental and socio-economic challenges in the future and the desperate attempt to protect available valuable natural resources are highly sought (Tompkins and Adger, 2004). The United Nations has called for a comprehensive framework for action through the high level task force on global food security and called for addressing the climatic impacts threatening future food and nutritional security (United Nations, 2011). The climate change processes and its effects are incremental and cumulative and affect the planet's ability to sustain life. This has been a common problem, known for over half a century to the scientific elites, but not easily understood by common people, or the environmental activists or policy makers[1] were not really successful in mobilizing mass support to call for effective controls.

1.2 Climate Change: Riding through Poverty and Food Security

The developing countries, particularly in South and South-east Asian and African regions are the poorest, only having low to medium ranking in the human development index (HDI) except for Thailand and China (Human Development Report, 2008). Climate-related disasters affected about 2 billion people in Asia, representing about 40% of the total population in these countries (FAO, 2008). In the 2000s, Asian countries (India, Bangladesh, Pakistan and Vietnam) and African countries, for example Kenya, Ghana, Niger and Burkino Faso[2], have significant numbers of people affected by various climatological and hydrological disasters such as tsunami, cyclones, typhoons, flood, droughts, landslides and hurricanes among others.

Because agriculture is the mainstay of the majority of people in the region, any adverse impact on it will definitely affect their socio-economic well-being, increasing poverty and reducing food security. Impacts caused by climate-related risks affect directly the farming sector thereby threatening food security. Food security is affected in two areas: (i) by way of a diminished source of food supply and (ii) by reduced primary source of income. This is the case for around 40% of the world's population and an estimated more than 65% of the Asian and African population. Hence, adverse impacts on the capacity of farmers to produce food will have profound effects on rural livelihoods and food insecurity. According to the latest developmental statistics, an average of 25–30% of the population are already below the poverty line (Table 1.1).

The rural poor are affected by several extraneous issues over the years that act against the improvement of their socio-economic status. Among these factors, climate change or variability and associated changes have a direct impact. They also have indirect effects on rural livelihood and food security (Sanchez, 2000). Many scientists argue that the food-insecure countries face insecurity not due to diminishing production but due to disparity in accessibility to quality food (FAO, 2003). Global climate change projections now have a firm scientific basis, and there is a consensus among researchers of growing certainty that the frequency of occurrence of extreme events is most likely to rise (Table 1.2). This will lead to losses of productive assets, personal possessions, or even loss of life or livelihood. Low food security status of millions of people in disaster-prone areas of Asia will increase. The low income and most vulnerable populations are the ones who are expected to feel the effects of climate change, such as frequent incidence of extreme events and natural disasters. As a result, climate change is most likely to increase the vulnerability of poor farmers who are already struggling with land degradation, price hikes and other social risks (ADB, 2009).

A recent study by the International Labour Organization (ILO, 2011) suggests that there will be significant differences between middle- and low-income countries because of the way in which climate change affects agriculture-based livelihoods. Statistically, the phenomena of exodus of population from farm-based employment to non-agriculture are common globally in general and particularly in these continents.

Table 1.1. Developmental status of the study countries.

Indicators	India	Sri Lanka	Bangladesh	Thailand	Vietnam	China	Ghana	Kenya	Niger	Burkina Faso
Human development ranking[a]	135	73	142	89	121	91	138	147	187	181
Human development group[a]	MHD	HHD	MHD	HHD	MHD	HHD	MHD	LHD	LHD	LHD
Population below income poverty line (PPP US$1.25 a day) (%)	21.9	7.2	31.5	13.2	20.7	15.9	28.5	45.9	59.5	46.7
Co-efficient of human inequality[b]	22.7	14.2	28.7	20.0	15.0	NA	31.2	32.7	40.2	34.6

Source: [a]United Nations Development Programme (UNDP) (2011), [b]World Bank (2012). LHD = low human development group; MHD = medium human development group; HHD = high human development group. The values are latest estimates of countries by UNDP.

Table 1.2. Summary comparison of people under stress globally, in Asia and in Africa.

Indicators	Global observed and projected changes	Asia	Africa
Atmospheric temperature	The temperature has risen about 0.2°C per decade globally. Moderate scenario (B2) projects that temperature is likely to increase by 1.4–3.8°C in 2090–2099 from the base years of 1980–1999.	For Asia including South Asia the increase is 3.3°C in 2080–2099.	Decadal analysis of temperatures confirms a warming trend across the continent. Warming projections under medium scenarios indicate that extensive areas of Africa will exceed 2°C by the last two decades of this century.
Flood	Millions of people will face the wrath of flood due to climate change and sea level rise in the densely populated low-lying mega deltas of Asia and Africa.	Coastal and mega delta regions in South and South-east Asian countries are at high risk.	The flood is expected to rise in the coastal region of Africa, resulting in high risk for areas such as flood plains, wetlands and coastlines.
Water resource	Population pressure and land-use change, together with impacts of climate change, are expected to exacerbate the increased runoff and decreased water availability.	By the 2050s, freshwater availability in Central, South, East and South-east Asia, particularly in large river basins, is projected to decrease.	These are subjected to high hydro-climatic variability in space and time and will be a key constraint to continued development.
Drought	Globally, drought-affected area has probably increased since the 1970s. Most of the drought-affected areas are projected to face greater stress and distress on livelihood, and associated sectors such as agriculture, water energy and health will be adversely affected.	Precipitation has been decreasing, especially in South Asia with related impacts on livelihood, health and natural resources.	In East and southern Africa, there is medium confidence that droughts will intensify in the 21st century in some seasons, due to reduced precipitation and/or increased evapotranspiration.
Crop productivity	Globally, the potential for food production is likely to increase over a range of 1–3°C rise in temperature over the local average; above this temperature it is projected to decrease.	Asia contributing major share of total world's tropics and expected to impact significantly on crop production	Food security will be adversely affected by a very likely reduction in crop productivity.

Sources: IPCC Assessment Report 4 (IPCC, 2007; United Nations, 2011; World Resource Institute, 2012; IPCC, 2014).

According to several studies, climate change would reduce crop productivity especially in tropics or lower latitudes, affecting the population associated with it directly or indirectly. A reduction in production will negatively impact on the farming sector, threatening food security and livelihood. In identifying these perils, there have been several scoping studies on impacts and the national and international initiatives against this challenge. The assessment of national action plans on climate change and the implementation of this plan is a plausible way forward on future prospects of adaptation strategies (Adaptation Knowledge Platform, 2010a, b).

1.3 Climate Change and Micro-level Impacts

The international attention on the impact of climate change is of major concern among the stakeholders. Recognizing the impact is imminent and it is important to quantify and qualify how it affects different sectors, and also understand the ways that different socio-economic groups are attempting to cope and adapt to climate variability in particular and climate change in general. With a huge task of achieving the millennium development goals, climate change impact could cause things to go from bad to worse. This has resulted in a deliberate attempt by the international community to improve the understanding of climate science, impacts and mitigation and its discrepancies (ADB, 2009). Global mean temperatures have been rising since the last century, mainly by the accumulation of greenhouse gas emission to the atmosphere orchestrated majorly by anthropogenic activities. Along with temperature, the climate itself is perceived to be continuously changing all over the world. The Human Development Report (2008) states that climate change is one of the greatest challenges humanity faces and/or will be facing, and it is the world's most vulnerable populations who are immediately at risk (Box 1.1).

The impacts of climate change would add an additional burden to the poor smallholder farmers of semi-arid tropics of India. The region is already hapless, with low soil productivity, rainfall variability, water shortage or scarcity, and poor development in rural infrastructure, institutions and markets being major identified characteristics of the semi-arid tropics (Shiferaw and Bantilan, 2004; Bantilan and Keatinge, 2007).

FAO (2008) identified different livelihood groups that needed special attention in the context of climate change and these include:

Box 1.1. Poverty and vulnerability to climate change goes hand in hand

The extreme climatic events and slow continuous change could be a major threat to the rural communities. The consequences could be direct and indirect, impacting on agriculture, nutrition, health, socio-economic condition and natural resource base.

1. Direct impact: Severe and frequent climatic extremes will put more into the vulnerable category or push them down the order by adopting the coping response strategy of selling/divestment of productive assets such as land or livestock.

2. Indirect: Climatic extremes or shocks make the price for essential commodities shoot up and there is also confusion in investment, innovation and development intervention in climate uncertainties.

- Low-income groups in drought and flood-prone areas with poor food distribution and infrastructure and limited access during an emergency.
- Producers of crops that may not be sustainable under changing temperature and rainfall regimes.
- Low- to middle-income groups in flood-prone areas who may lose homes, stored food, personal possessions and means of obtaining their livelihood, particularly when water rises very quickly and with great force, as in sea surges or flash floods.

Changes in weather patterns, especially temperature and rainfall, in this region directly impact farming on which the majority of the population depends. Agriculture is majorly rainfed so changes in rainfall pattern would definitely result in a shortfall in yield and resultant income. Future climate change projections for the Indian subcontinent have shown a disturbing figure of 3–6°C with wide variability in quantum, distribution and onset of rainfall (NATCOM, 2009). In India, particularly in the semi-arid tropics, climate change impacts on crop have been studied extensively and adaptation was only confined to field level. The last stakeholder that is at the receiving end and experiences the wrath of climate change is the farmer. Farming in the semi-arid tropics is majorly rainfall dependent; fluctuations definitely impact on their farming and farming decisions. This could indirectly affect output from farming and ultimately have socio-economic effects. Farmers have, however, been adapting to these changes from the inception. These autonomous adaptations are comparatively slow and less effective.

Several studies have been undertaken to gain insight into micro-level opportunities and constraints, along with understanding how the farmers perceive the impact of climate change vulnerability and elasticity of degree of resilience among the farmers' strata, etc. Studies with a socio-economic perspective are highly recommended to be successful to cope against climate change, particularly targeting the most vulnerable group (Adger, 2003; Adger *et al*., 2005). These studies attempt to capture the way rural folk are affected by climate change and to understand their coping strategies and constraints faced, if any. These field level insights and findings could be a stimulus to the policy makers in formulating programmes for the target regions and improving and developing strategies against climatic risk. Several coordinated studies including the research conducted by the Climate Institute (Washington, DC) pointed out the importance of these studies in these regions because they are most likely to be hardest hit by the consequence of global warming and climate change leading to serious implications for the livelihood of poor farmers in the most vulnerable countries. The issues to be discussed will certainly follow from here and there.

When shocks do occur, people employ a wide range of coping strategies, but these may involve incurring debt or selling assets, which may leave people more vulnerable to future shocks. All the coping decisions are based on the availability of opportunities but also on how capital/finance is accessible to the farm households. To support the increasing population and households to pull them out of poverty, it is important both to reduce their exposure to shocks and to strengthen their resilience by enhancing their individual and collective capabilities and by addressing these interlocking disadvantages. With the proliferation of smallholder farmers in semi-arid tropical India, understanding the trend of the situation in terms of the extent of vulnerability to extreme events, such as drought, through ex-ante assessment is useful to understand the pattern of vulnerability for efficient planning and action. The study by ICRISAT (2012) was aimed at improving understanding of how environmental, agro-socio-economic factors contribute to the livelihood vulnerability of rural, agricultural and natural resource dependent communities in the region. This analysis will be useful in formulating policy recommendation (for planners and development agencies) to target sections on improving the adaptive capacity, thereby minimizing vulnerability in their responses to drought.

1.4 Organization of the Book

There are many studies on the micro-level understanding of various implications of climate change. However, studies related to regions that are highly vulnerable in the south, South-east Asia and China are limited. In this context, this book focuses on semi-arid tropical regions of India, flood-prone and drought-prone regions of Bangladesh, dry regions of Sri Lanka, vulnerable regions of Thailand and Vietnam, and dry regions of China. This is a compendium of the micro-level experiences, analysis and perception of farmers on climate change and trends in agro-socio-economic indicators of the region. This book is majorly the results of the regional project 'Vulnerability to Climate Change: Adaptation Strategies and Layers of Resilience' supported by Asian Development Bank (ADB) and other studies in Africa conducted under the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The ADB supported project aimed to provide science-based solutions with a pro-poor approach for adaptation of agricultural systems to climate change, for the rural poor and most vulnerable farmers in semi-arid regions of Asia, especially of India, Sri Lanka, Bangladesh, Thailand, Vietnam and Peoples' Republic of China (PRC). The overall objective of the project was to identify and prioritize regions most at risk and to develop gender-equitable agricultural adaptation and mitigation strategies as an integral part of agricultural development in the most vulnerable areas. This research was done with a goal to improve innovations in agricultural institutions, crop and resource management, role of women, social capital and social networks in these study countries. The study takes into consideration the context variability among and within the countries' cases and how best to analyse by identifying elements of an ideal governance framework where adaptation can be optimized. The project generated valuable outputs that had policy and livelihood impacts. It was also involved in developing a useful information repository to inform policy decisions on critical issues affecting the future of agriculture and livelihoods in these vulnerable regions.

The organization of the book is as follows: Chapter 1 is on the introduction to climate change vulnerability and adaptation strategies with rural farm-level perspective. Chapter 2 discusses the analytical framework and methodologies for analysing farm-level vulnerability in the region. Chapter 3 examines the trends of climate and extreme events in the region and expounds on the critical question of what is the extent of changing climate. Chapter 4 gives the results of farmers' perception on climate and socio-economic trends with respect to climate change. Chapter 5 gives a meso- or macro-level perspective of climate change on food security in Asia and Africa. Chapter 6 evaluates crop-level adaptation options to current and future climatic trends using crop simulation experiments and Chapter 7 assesses the impact of climate change adaptation strategies for small farmers in Kenya, Africa. This study used the Tradeoff Analysis model for Multi-Dimensional Impact Assessment (TOA-MD) for assessing impacts. Chapter 8 gives the results of farm-level analysis of climate change adaptation from Niger and Burkino Faso. Chapter 9 gives details of importance of sociological studies in understanding climate change resilience among communities and their coping strategies. Chapter 10 describes the results of the analysis in identifying policy options towards climate resilience in Ghana, Africa. Chapter 11 is a synthesis of key messages from the micro-level analysis and identifies constraints and opportunities in adaptation, and the final chapter, Chapter 12, gives the key recommendations for enhanced options for adaptation against climate change and furthermore in strengthening the path towards climate resilience in the region.

Globally, efforts undertaken in understanding micro-level adaptation strategies to climatic change and variability are comparatively less than those of macro-level/regional studies. This book tries to fill these gaps and covers countries that are highly vulnerable to climatic changes in Asia and Africa. This one of its kind investigates to the bottom of the strata, i.e. household, in identifying gaps, limitations and potential in improving the resilience to climatic changes. This book also forecasts impacts (crop and economics) to slow changes in climate (temperature and rainfall). The country-specific studies are available, but compendiums of country-specific case studies with regional perspectives that this book is aimed at are limited. The book is an attempt to weave together different dimensions and facets of climate change and its impacts, thereby enabling the planners and development practitioners to visualize/concretize the adaptation pathways for enhancing the grass-root-level resilience to climate change. The uniqueness stems from the fact that the strategies are evolved from farmers' experiential knowledge and perception against scientific know-how based on climatic data analysis. Furthermore, the book comprehensively focuses on how household indigenous knowledge helps communities to adapt and cope. Does perception on climate change translate to behavioural change or adaptive measures at the micro-level across the study countries? In a nutshell, it intertwines the traditional, local and indigenous knowledge on climate change with scientific knowledge on climate change in an attempt to provide concrete leads for building climate-resilient agriculture.

Notes

[1] This highlights the failure of mobilizing support for the Tokyo Protocol and related international instruments among law makers in developed as well as developing countries and the difficulty of the UN pushing environmentally related conventions and follow-up action by member governments.

[2] These African country studies are focused on in this book.

References

Adaptation Knowledge Platform (2010a) *Scoping Assessment for National Implementation in Thailand*. Regional Climate Change Adaptation Knowledge Platform for Asia, AIT-UNEP RRC. AP, Bangkok, Thailand, p. 36.

Adaptation Knowledge Platform (2010b) *Scoping Assessment on Climate Change Adaptation in Vietnam*. Regional Climate Change Adaptation Knowledge Platform for Asia, AIT-UNEP RRC. AP, Bangkok, Thailand, p. 20.

ADB (2009) *Building Climate Resilience in Agriculture Sector in Asia and the Pacific.* Asian Development Bank, International Food Policy Research Institute, Manila, Philippines, p. 304.

Adger, W.N. (2003) Social capital, collective action, and adaptation to climate change. *Economic Geography* 79(4), 387–404.

Adger, W.N., Arnell, N.W. and Tompkins, E.L. (2005) Successful adaptation to climate change across scales. *Global Environmental Change* 15, 75–86.

Bantilan, M.C.S. and Keatinge, J.D.H. (2007) Considerations for determining research priorities: learning cycles and impact pathways. In: Loebenstein, G. and Thottappilly, G. (eds) *Agricultural Research Management*, Springer, Netherlands, pp. 37–64.

FAO (2003) *Conceptual Framework for National, Agricultural, Rural Development, and Food Security Strategies and Policies*. Stamoulis, K. and Zezza, A. FAO, Rome.

FAO (2008) *Climate Change and Food Security: A Framework Document*. Food and Agriculture Organization of the United Nations, Rome.

Human Development Report (2008) Human Development Report 2007/8. Fighting Climate Change: Human Solidarity in a Divided World. United Nations Development Programme. Available at: http://hdr.undp.org/en/content/human-development-report-20078 (Accessed 22 June 2015).

ICRISAT (2012) *Tracking Adaptation Pathways and Identifying Strategies for Enhancing Grass-Root Resilience to Climate Change*. Synthesis Report, Vulnerability to Climate Change: Adaptation Strategies and Layers of Resilience, International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Hyderabad 502324. pp. 259.

ILO (2011) *Global Employment Trends 2011. A Challenge of Job Recovery*. International Labour Organization, Geneva, Switzerland.

IPCC (2001) *Climate Change 2001: Impacts, Adaptation and Vulnerability*. IPCC Third Assessment Report, Cambridge University Press, Cambridge, UK and New York.

IPCC (2007) *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability*. Synthesis Report. Summary for Policymakers, Inter-Governmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

IPCC (2014) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., *et al*. (eds)). Cambridge University Press, Cambridge, UK and New York.

NATCOM (2009) *India's National Communication to UNFCCC. Data Extraction Tool for Regional Climate Scenario (PRECIS) for India*. Ministry of Environment and Forests, Government of India.

Sanchez, P.A. (2000) Linking climate change research with food security and poverty reduction in the tropics. *Agriculture, Ecosystems and Environment* 82, 371–383.

Shiferaw, B. and Bantilan, M.C.S. (2004) Agriculture, rural poverty and natural resource management in less favored environments: revisiting challenges and conceptual issues. *Food, Agriculture & Environment* 2(1), 328–339.

TERI (2005) *Adaptation to Climate Change in the Context of Sustainable Development, Background Paper*. The Energy and Resources Institute (TERI), New Delhi, India.

Tompkins, E. and Adger, W.N. (2004) Does adaptive management of natural resources enhance resilience to climate change? *Ecology and Society* 9, 10–23.

United Nations Development Programme (2011) *International Decade for Action. Water for Life, 2005–2015*. Available at: http://www.un.org/waterforlifedecade/scarcity.shtml (Accessed 22 June 2015).

World Bank (2012) The World Bank. http://data.worldbank.org/ (Accessed 22 June 2015).

WRI (2012) World Resource Institute. Available at: http://www.wri.org/ (Accessed 22 June 2015).

2 Analytical Framework and Methodologies for Analysing Farm-level Vulnerability

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Abstract

A comprehensive and well-thought-out framework of analysis is a pre-requisite in analysing pathways in improving resilience to climate change. This chapter discusses the analytical framework that includes macro data analysis, modelling, social analysis, etc., with an inclusive Q^2 approach. All information gathered is from primary data collected through questionnaire surveys, focus group discussions and personal interviews. The analytics adopted include: climatic analysis; vulnerability analysis; farmers' perceptional analysis and matching perceptions with reality; social analysis including gender and social networks; and regional assessment of climate change impacts on agriculture using an integrated modelling approach.

2.1 Introduction

Several studies have been undertaken to gain insight into micro-level opportunities and constraints, along with an understanding of how the farmer perceives the impact of climate change and variability and elasticity of degree of resilience among the farming strata. Although related studies have been undertaken in West Africa (Mertz *et al*., 2009), eastern Africa (Hisali *et al*., 2011; Below *et al*., 2012), southern Africa (Thomas *et al*., 2007; Patt and Schroter, 2008; Stringer *et al*., 2009; Bunce *et al*., 2010) and South America (Simeaos *et al*., 2010), similar studies should be done in Asian countries including the sociological perspective of climate change. This is highly recommended to be successful to cope with climate change, particularly targeting the most vulnerable groups (Adger, 2003; Adger *et al*., 2005). This synthesis attempts to capture the way rural folk are affected by climate change and understand their coping strategies and constraints faced. These field level insights and findings could be a stimulus to the policy makers in formulating programmes for the target regions and improving and developing strategies against climatic risk.

The global climate change watch mechanisms have been sounding alarm bells since the 1960s, warning of rising global temperatures due to greenhouse effects, rising sea

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levels, and changes in quantum, patterns and intensity in rainfall. There is concern that the most affected will be those most vulnerable, i.e. the poor. The Asian region hosts 55% of the world's population, which is about 3.8 billion people. In Asia 62% of its people directly depend on agriculture; a further 25–30% of the people live below the poverty lines. An increase in air temperature will have a negative effect on crop productivity and yield, as well as farm incomes. In Asia, a large number of people will be directly affected by way of their livelihoods and incomes owing to their vulnerability. People with least resilience to withstand the adverse changes and climate shocks are the poor. Rising urban and elderly populations will further strain the countries, resulting in possible conflicts and political instability. On the other hand, it is well known that at the village-level there is a vast pool of experiential and traditional knowledge that helps people to survive, adapt to changes and continue with their lives.

In this context, the key research problems are addressed as follows:

1. What are the key climatic changes taking place in the Asian region? To what extent are the trends significant?
2. What are the key changes taking place at the grass-roots level, as climate being a major driver of change?
3. Do the changes inferred through analysis of climate data match with the experimental learning and shared knowledge of vulnerability with regard to the village communities?
4. How do people respond to these changes with their acquired experiential knowledge and available institutional support?
5. What measures and support will help to improve the resilience and coping mechanisms of vulnerable groups?

2.2 Objectives

The project described here is aimed[1] at providing science-based solutions with a pro-poor approach for adaptation of agricultural systems to climate change, for the rural poor and most vulnerable farmers in semi-arid regions of Asia, especially of India, Sri Lanka, Bangladesh, Thailand, Vietnam and the Peoples' Republic of China (PRC). The overall objective of the project is to identify and prioritize regions most at risk and to develop gender-equitable agricultural adaptation and mitigation strategies as an integral part of agricultural development in the most vulnerable areas. This research is done with a goal to improve innovations in agricultural institutions, crop and resource management, role of women, social capital and social networks (Adger, 2003) in these study countries. The study takes into consideration the context variability among and within the countries' cases and how best to analyse by identifying elements of an ideal governance framework where adaptation can be optimized. The descriptive framework for addressing the climate change agenda is given in Fig. 2.1.

The project aims to generate valuable outputs that will have policy and livelihood impacts. It is also developing a useful information repository to inform policy decisions on critical issues affecting the future of agriculture and livelihoods in the rainfed semi-arid tropics (SAT). For this to happen a robust approach is needed with reliable and in-depth understanding and a minimum set of key information (Vincent, 2007; Aggarwal *et al*., 2010). Hence this project pitches for enhanced information from different components of analysis, argumentation and advocacy (Kelly and Adger, 2000; Adger and Vincent, 2005).

The key outputs of the project include: (i) an improved understanding of the climate variability (and other related factors) that may be influencing changes in cropping patterns, crop yields, structures of income and employment, and adaptation-coping strategies of the rural poor in SAT villages; (ii) best practices and institutional innovations for mitigating the effects of climate change and other related shocks; and (iii) strategies to address socio-economic problems relating to changing weather patterns and availability of a range of initiatives for their alleviation.

2.3 Formalizing Concepts

The framework presented below is developed to analyse the problem and present the

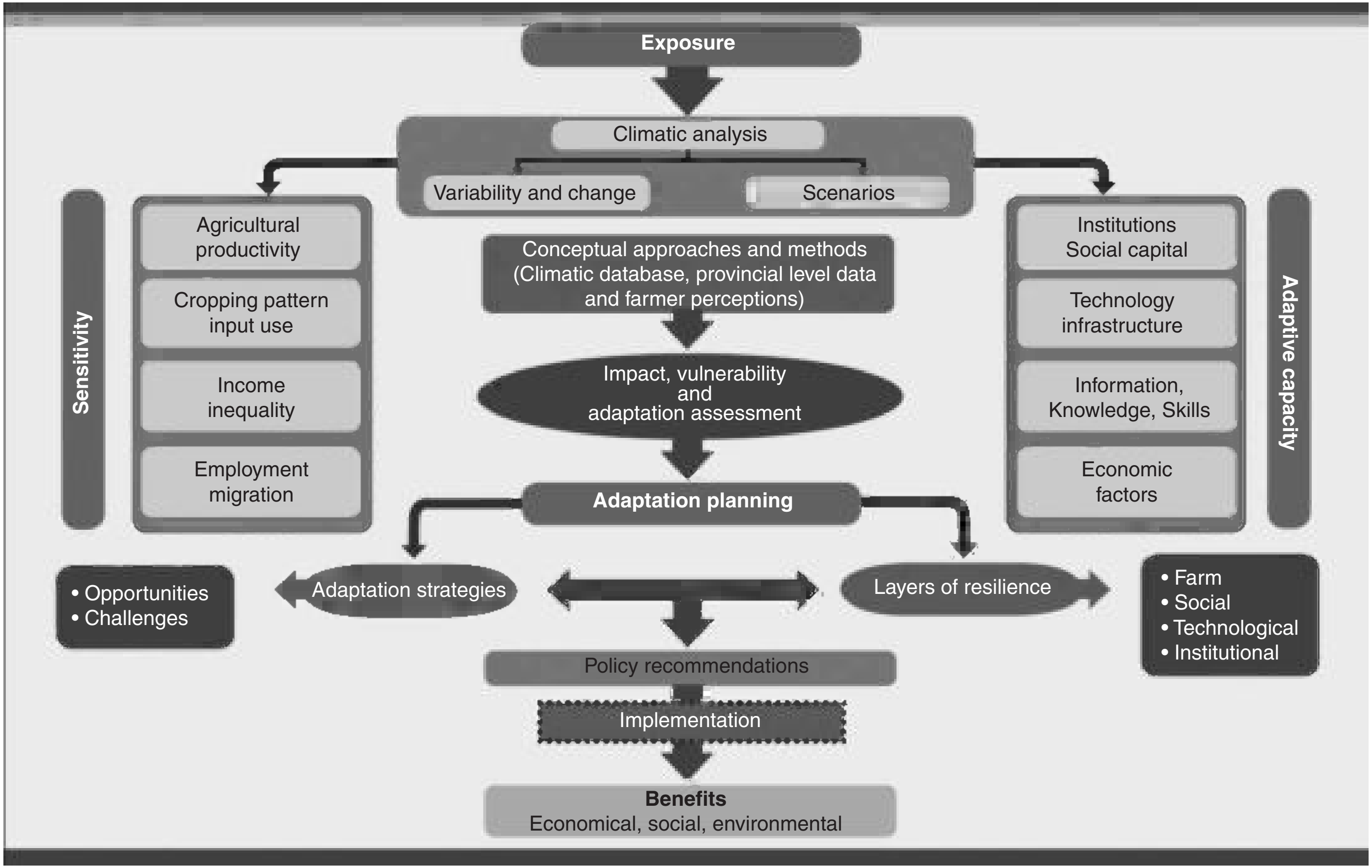

Fig. 2.1. Conceptual framework for addressing climate change agenda.

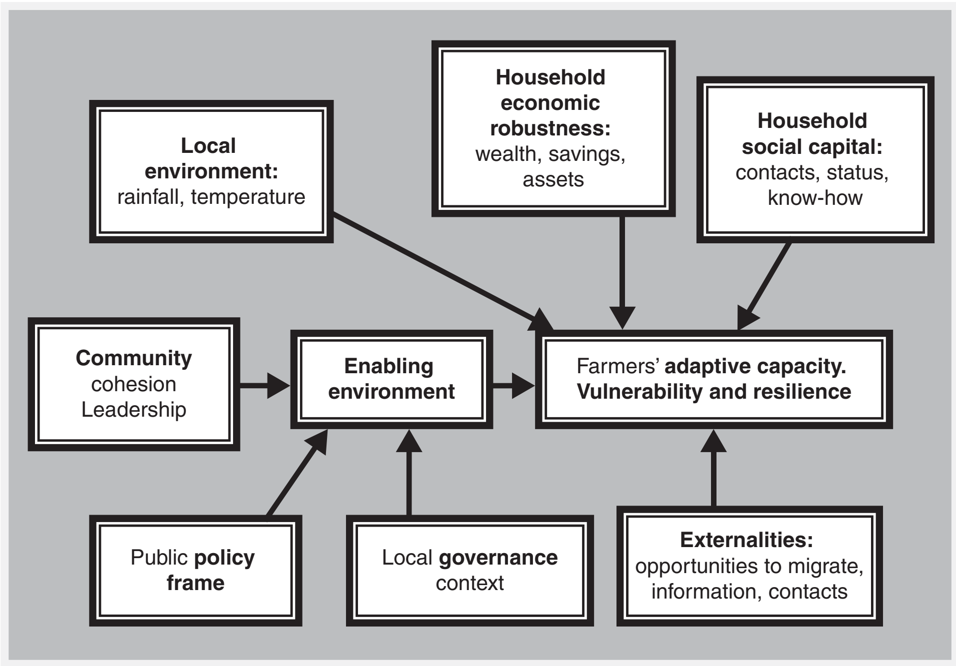

Fig. 2.2. Inter-linkages explaining the influence on adaptive capacity to climate change at micro-level (village).

research design to assess the situation and identify methods of adaptation (Fig. 2.2). The process will enable us to present policy suggestions to the participating countries to follow up on.

The climatic conditions continue to change. The continued greenhouse gas emissions, deforestation associated with urbanization, energy consumption and over reliance on non-renewable energy put the fragile environment balance at high risk. In the Asian region, large groups of people will be adversely affected if the present trends in climatic change continue. Increases in temperature, rainfall and unpredictable nature manifested in extreme occurrences that are becoming more frequent will affect the lives of millions of people. The ability to cope and adapt to these changes will depend on many factors. Most of these factors are beyond the scope of the realm of influence of local farmers in the region. The adaptive capacity if enhanced will enable them to cope with minimal state interventions. There will be considerable variability in the ability of farmers to adapt and adjust. The figure (Fig. 2.2) places in perspective the important factors that have a bearing on the ability of farmers to cope. The conceptual model does not imply causation but visualizes relationships that were examined.

Insights on impacts, the section of population affected, extent of effects, changes in biophysical patterns, changes in socio-economic status and so on are to be gained through these analyses. The impacts could be experienced at different levels of influence, i.e. household, community and governance (Fig. 2.3), and at each level there should be an effective mechanism in place to cope with climate change effects at different levels of aggregation. Households will respond differently to these changes. They will depend on the individual household, the community infrastructure, access and existing macro-level policies and also on the ground programmes available. Identifying the right indicators is always a challenge and varies with scales of interference and interaction (Vincent, 2007). We hypothesize that all the villages in the SAT are different from one another in biophysical and socio-economical conditions and the available programme that is meant to enhance their coping ability with available support, networks and relief (Yohe and Tol, 2002). Our effort is, however, to pick common threads of opportunities and constraints and to enable them to equip themselves against climate-related risks. The response could be of different efficiencies: (i) at suboptimal level at household, community or governance structures; (ii) at optimal level, could respond effectively to climate change and related shocks; and (iii) at above optimal level. The developmental agencies should push communities to a higher level of capacity to respond optimally and to be resilient enough to cope with the expected climate changes.

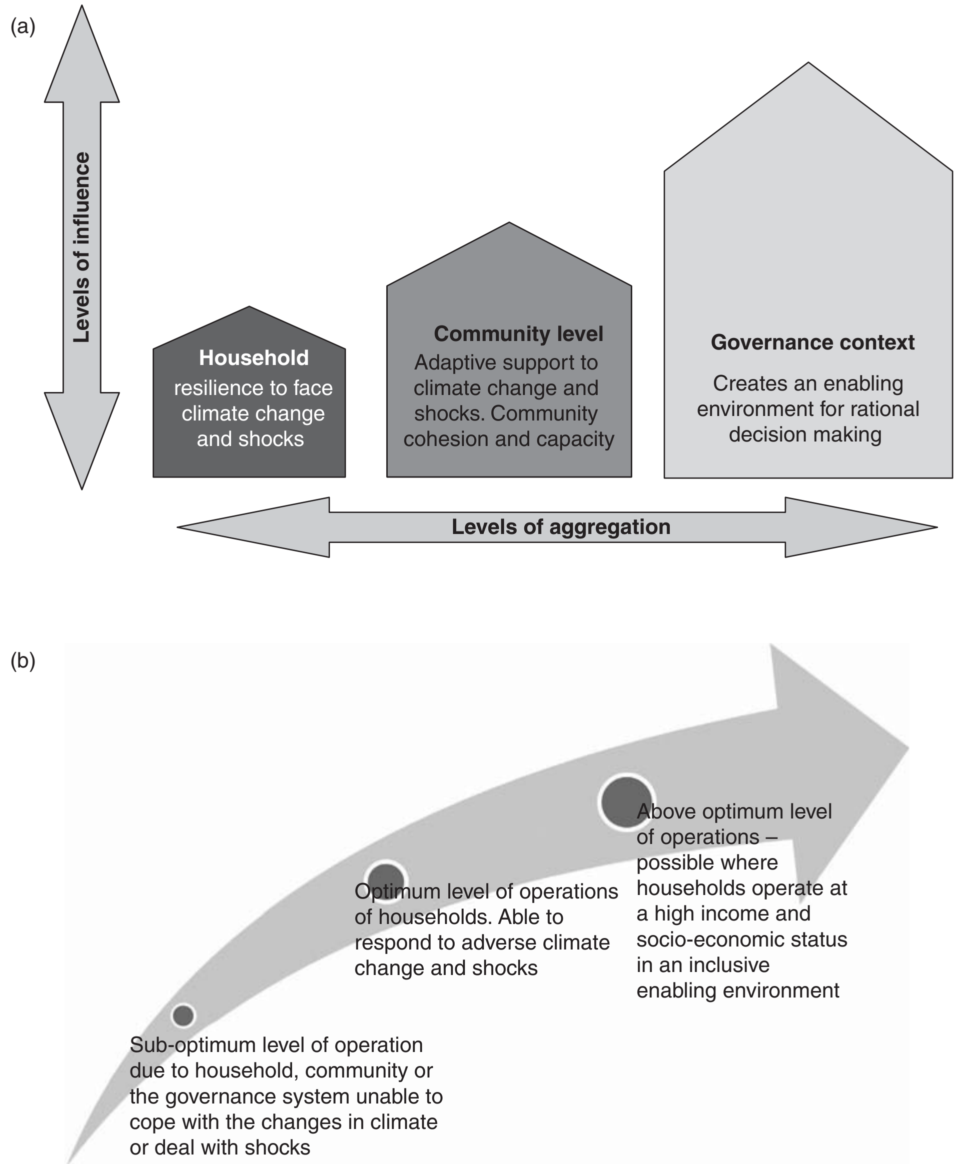

Fig. 2.3. Levels of interventions that have bearings on farmers' potential to cope with the effects of climate change. (a) Levels of influence; (b) Levels of optimal actions.

2.4 Farmers' Adaptive Capacity

With reference to Fig. 2.2, a multitude of agro-socio-economic factors contributes to the power to adapt to the crisis. Adaptation to the slow and extreme changes in the climate is necessary to ward off the negative consequences resulting from it. So, an adaptation is defined as a response to actual or expected climate stimuli or their effects, which moderates harmful effects or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private or public adaptation, and autonomous and planned adaptation. The capacity, on the other hand, is the ability of a system to adjust to change, to moderate potential damage, to take advantage of opportunities or to cope with the consequences.

Climate change and its effects are slow in their manifestation. The three key indicators that this study used are: (i) rainfall, (ii) temperature and (iii) climate shocks. The intensity and the onset of rainfall, and the number of days of rain, have a bearing on the lives of farmers in terms of addressing both household and farming requirements. Farmers dependent on water for their cropping and livestock rearing will suffer losses if rainfall is insufficient. On the other hand, an increase in temperatures has been reported worldwide, which not only adds to discomfort, but also to evapotranspiration, thus affecting crop productivity and moisture availability.

Farmers may adopt a range of strategies and practices to cope with the changes they experience in their environment. These changes may be a reaction to experiential knowledge and may not necessarily be associated with a rational awareness of the complexities of the environment cycle. Adaptive strategies may be adopted at an individual farm household level or as collective efforts undertaken by villagers.

The adaptive efforts may also be in terms of: (i) changes in the technology adopted at the farms; (ii) reallocation of resources at the household level, i.e. savings, food stores and assets; and (iii) relocation to a new environment or diversifying the life base to gain benefit from other opportunities (Table 2.1).

2.4.1 Farmers' vulnerability/resilience

A related concept that explains adaptability is farmer vulnerability defined as the degree of susceptibility to adverse changes. Vulnerability is a function of the character, magnitude and rate of change to which a system is exposed, its sensitivity and adaptive capacity. It is also the ability to cope with the external threats. The vulnerability to external negative stimuli such as climate changes and shocks will depend on several intra-household factors such as: (i) household economic robustness and (ii) household social capital.

2.4.2 Household economic robustness

The ability to face any difficult situation in the village is often determined by the economic status of the farmer or the household. In the context of climate change or shocks, it is very plausible that the well-to-do farmers can adapt best and take care of their interests most effectively. Although the economic nexus is a key determinant, it also provides an opportunity to push forward a local agenda that ensures economic development of households in a more equitable manner. Thus with greater food reserves, savings and disposable wealth, more households will be capable of withstanding shocks and disasters associated with climate change. Diversifying income sources, i.e. so they are not solely dependent on farming alone, will reduce risks and vulnerabilities.

2.4.3 Household social capital

It is at the household level that the farmers are most likely to adapt to any shocks or trends of climate change. It is here at the family level that the day-to-day livelihood

Table 2.1. Matrix of climate resilient levels of actions: the ideal, actual and desired actions.[a]

Level of actions	Ideal	Actual	Desired
Household 	Adequate wealth and assets to manage needs Sufficient social capital to mobilize resources, patronage or obtain know-how Sufficient savings – income and/or food Knowledgeable, competent to sustain livelihoods and adapt to context change	Inadequate assets and wealth to meet basic needs Marginalized and disenfranchised No savings of food or income Limited world view and unable to adapt to changing situations on location	Capacity to improve asset base to address needs in a sustainable manner Improve know-how and competencies to deal with climate change and shocks
Community 	Cohesive and inclusive Effective leadership to mobilize community Differentiated to have required competencies to share skills and address common needs Available and access to markets to trade required goods and services	Fragmented Leadership self-serving or non-representative Low competency and skill base Low access to or prevalence of markets	Collective awareness of the need for community-based efforts to mitigate climate change and shocks Individuals and groups engage in improving their collective capacity
Country governance context 	Efficient service delivery system Responsive to local needs Inclusive and fair Ensure access to information and services in an equitable manner Effective principle of subsidiarity	Ineffective service delivery system Non-responsive to local needs Directed towards selected audience Community interests and needs decided at the top	Regions adequately linked to the state service delivery system Strengthen local agency for decision making Effectiveness and efficiency improved to bridge any gaps in expectations and variability at local level

[a]Identified and compiled from the study.

decisions are taken. The level of know-how will determine how effectively the family will react to any deleterious effects of climate change or associated shocks. The greater the knowledge and competencies, then the greater the ease with which they will be able to adapt. The information related to climate change and shocks that are to be experienced, what is suggestive as reaction, what ways are known and are being suggested to the people, what support programmes are available and so on, will be accessible to people with contacts at relevant personnel and agencies. The social status and competencies of the farmers will also determine the ease with which they obtain the external support available.

2.5 Enabling Environment

In modern times state formation is a parallel process to development. In all countries the writ of the state is becoming more dominant and pervasive. All countries espouse a strong, accountable and effective state. The ability of farmers, community-based organizations and local agencies to act effectively and in the interest of the local residents depends very much on the 'space' created for such work. With increasing writ of the state being asserted in the periphery, most services will be delivered by the state, minimizing the scope for local engagements. The state can, however, also benevolently legislate local involvement of participation.

Given the diversity and complexity of local situations, it is not practical or feasible to obtain total understanding of a local situation. State planning cannot be done effectively from the centre with minimum engagement of the periphery or the local communities or their representatives. The state should provide effective capacity development, resourcing and instituting in a process that enables local participation to improve the validity and relevance of externally facilitated processes. These can include adaptation to climate change, livelihoods and taking preventive measures in preparation for deleterious effects of climate change or climate shocks.

2.5.1 Public policy frame

Consistency, continuity and coherence are ensured by a clear policy frame. In the context of minimizing negative effects on farmers and marginalized communities from climate change and related shocks, the interest in safeguarding the most vulnerable must be enshrined in clear policy commitments. Failure to do so will divert attention and deflect government and public interest. If not addressed effectively, future impacts will have negative consequences of a larger magnitude. It is therefore necessary to identify a policy frame that enables people's participation, promotes good governance, and promotes investment in strategies and programmes to minimize negative impact; such a framework must be agreed upon and adopted.

2.5.2 Community cohesion

Farm families live in the context of village communities, which are characterized by a web of social relationships. These relationships are economic, social and historical. Caste, class, socio-economic status, gender and age are well-known dimensions along which communities are stratified. In the modern world, occupation, language, political affiliations and patronage, access to information and ICT, overseas capital flow due to migration, social contacts, among others, also add further dimensions to stratification. There are numerous ways in which communities are differentiated too. Differentiation by neighbourhoods, institutional affiliations, occupations and membership in social groups, such as professional and vocational associations, etc., makes communities complex. This complexity also provides a basis for cohesion and collective ethos. At a symbolic level, communities will have clear demarcation of territorial boundaries, names and other forms in which they develop identity. A cohesive community will be able to identify leaders, identify goals of collective interest, and steer these processes to achieve targets rather than those that may be fractioned and in conflict.

Communities that have different organizations addressing the needs of its members strengthen the people's sense of community and will be able to address the needs of the members more effectively. Thus in the context of climate change and the deleterious effects that villagers may have to face, a cohesive community led by well-informed and well-meaning leaders will be able to address their needs more effectively than communities that are not cohesive and do not have an effective leadership structure.

2.5.3 Local environment

The need to adapt to climate change is felt because of the realization that the extremes of weather changes experienced at present are a result of long-term climate change. National-level aggregated data analysis shows trends and changes. Some changes are significant, whereas others may be more suggestive. There may be patterns emerging in terms of climate-related shocks that have catastrophic effects on people, property and economies.

Given the wide variability in agroecological situations within each country and also among the countries, the need for location specificity in interventions is imperative. The trends and mean analysis may mask and distort what is experienced at the local level. The local changes must therefore be analysed and compared with the national aggregates when drawing inferences, conclusions and recommendations.

Another key factor that will have a bearing on the effects of climate change and availability of rainwater is human intervention in transmitting water from areas with an oversupply to areas with an undersupply. The ambitious Indian National River Linking Project (INRLP)[2] started in 2006 where waters from perennial rivers were to be diverted to seasonal rivers was one of such initiatives proposed to be a solution to the specific problem in the future. When implemented, the water balance situation in large tracts of now arid regions will change and will have bearing on the utility of land for farming. When this occurs, uncultivable land owing to climatic conditions of low rainfall will change drastically. This is an extreme example and there is a need to examine more closely the local context when drawing inferences of climate trend, and analysis is important.

2.5.4 Local governance

The ability of farmers to cope and adapt to a great extent depends on the governance system that prevails in the localities and the connectivity to the national governance system (Agrawal, 2008). Practice of good governance or best practices by all governance bodies will result in the best alternatives of livelihoods provided to the people. An enabling environment for people to participate freely in governance ensures more positive outcomes such as reduction of poverty, famine and economic development.

In most Asian countries, there are governance structures permeating to the village level that enable people's participation, such as the Panchayat Committees in India, the Pradeshiya Sabhas in Sri Lanka,[3] and other village development societies. These groups ensure that governance systems are close to the people. Engaging in these structures enables people to steer local development planning in key areas such as agriculture, livestock, infrastructure and community development, forestry, green practices, and disaster mitigation and management. The more engaged the agencies are at the local level, the more likely local needs are served.

This is the principle of subsidiary, which is to enable decision making at the level where they have the greatest effect. Hence, an irrigation canal development project for a village is best undertaken at the local level where the beneficiaries are. If the local governance system is functioning well, then the principle of subsidiarity will apply at an optimal level. The climate change effects can then be better addressed with meaningful strategies specific to every locality, rather than blanket policies or programmes. The programmes and strategies must recognize this variability in terms of quality of governance system and extent of local participation. The conceptual ideal is where the principle of subsidiarity is applied fully under good governance.

2.5.5 Externalities

All villages and households are interconnected in a wide web of socio-economic relationships further enhanced today due to inroads in ICT that connects even the remotest human settlements. Thus with access to information, people can expand their world-view and live in different locations to escape risky, violent and unsustainable environments.

The extent to which the externalities are optimally used will be dependent on the availability and access to information relating to the external contexts and opportunities. This may be enhanced due to social contacts already available or through persons already in the new locations or via information trickling from others who are aware of such opportunities (Jackson, 2005). Thus the above framework provides the direction and focus for investigation and analysis.

Continuous crop or livestock failures, depletion of savings and assets, non-availability of a local support system and state patronage to cushion climate shocks will prompt many to leave their village and migrate.[4]

2.6 Study Approach and Methodology

This study involves six countries with varying institutional capacity for climate and socio-economic data collection and analysis.

A summary of the methodology adopted for each of the key research outputs is presented below and elaborated in Table 2.2. A systematic planned methodology was adopted for this study and it was uniformly followed for all the countries. Five rounds of training and coaching support were provided to the lead partner organization on: (i) climate data and socio-economic quantitative data analytical methods; (ii) geo-statistical environmental data analysis; (iii) qualitative data collection and analysis; (iv) crop-environmental modelling; and (v) econometric modelling to assess climatic impact on net revenue. This was undertaken to ensure uniformity in research processes and outputs among the six country cases. However, as data sets were limited in some country cases, findings for these countries are analysed from a regional perspective. The research approach encompasses all the three components of climate agenda: namely exposure, sensitivity and adaptive capacity.

The activities of the project include:

1. Collection and analysis of secondary data on weather parameters, and on cropping patterns, incomes, employment, consumption levels, enterprise economics, etc., from representative samples of target countries.
2. Survey and comparison of farmers' perceptions about climate change and variability compared with detailed trend analyses of long-term climate data from nearby stations.
3. Assessment and analysis of past and present adaptation practices, using a social lens, along with biophysical lens to identify what works and what does not.
4. Mapping alternate channels and institutional arrangements for strategies and mechanisms to mitigate the effects of climate change.
5. Documentation of changes, if any, related to climate variability; and report of the cause-and-effect relationships between changes in cropping patterns and productivity levels, changes in weather parameters, length of growing period, policy changes and institutional innovations on the other, employing appropriate statistical tools.
6. Preparing policy briefs and conducting policy workshops to advocate the necessary policy changes to alleviate poverty and reduce the impact of income shocks caused by weather aberrations.

India and Bangladesh had a similar case, which boasted of long-term panel data sets that complemented the analysis in capturing various dimensions of village dynamicity. The agricultural economy of Bangladesh is predominantly based on rice in a water-rich environment; more information and related literature is captured on these facets than on the water-scarce phenomena such as drought in the semi-arid environment. Sri Lanka, Thailand and Vietnam undertook cross-sectional analysis and were successful in eliciting most of the information required to accomplish the objective of the study. For China, it was the continuation of the acquired experiences of adaptive research from RETA 5812 on watershed development. It was felt in the beginning that the good rapport of the team developed during the implementation of the previous RETA 5812[5] would aid in capturing the grass-roots information more effectively. But, in spite of the various training for capacity building, some of the critical dimensions of crop simulation and estimating of economic impacts could not be captured owing to:

- Unavailability of minimum input data sets of the study region for carrying out this type of analysis using DSSAT

Table 2.2. Indicators and methods for evaluation/assessment.

	Research outputs	Methods
1	Trends in:	
	Rainfall	Longitudinal data analysis of all six countries for last 40 years. Using TRENDZ software of CRIDA, India. In each country the meteorological / climate data were collected from all available government sources from meteorological and agriculture departments.
	Temperature	Longitudinal data analysis of all six countries for last 40 years.
	Shifts in onset and conclusion of cropping seasons	Based on rainfall data analysis
	Occurrence of extreme events	Assessing linear trends and any deviations in rainfall and temperature
2	Vulnerability assessment: Identify regions and populations that are at risk due to climate change	Indexing drawing from IPCC method, i.e. exposure, sensitivity and adaptive capacity. In each country, depending on availability of data, appropriate measures were used.
3	Estimates of crop yield losses and productivity	Crop modelling was done for selected locations in India and Vietnam. India – four locations (Mahabubnagar and Anantapur district in Andhra Pradesh; Akola and Solapur district of Maharashtra state); Vietnam – eight agroecological zones.
4	Economic climate change impact analysis	Using the Ricardian approach (Mendelsohn *et al.*, 1994) in Andhra Pradesh district of India and the north-east region of Thailand.
5	Adaptation strategies	
	At household level Collective Governance context changes	Household surveys in villages in the climate high-risk locations in each country. Bangladesh (4 villages) India (6 villages) China (2 villages) Sri Lanka (4 villages) Thailand (4 villages) Vietnam (2 villages) Survey of households based on two questionnaires – quantitative and qualitative Focus group discussion (FGD) in each study village Key informants interviews While in all countries the locations were chosen from the semi-arid zones, in Bangladesh 2 villages were from flood-prone areas.
6	Understand the social dynamics of adaptation	Drawn from the FGDs, household survey, key informants and published sources
7	Catalogue of adaptation strategies that may be applied in Asian context	Identified from the list of case studies undertaken from the research project
8	Asia region and country-specific policy briefs	Policy inferences drawn from studies, reviewed by panels within the country and at a regional plenary session and finalized with in-country stakeholder participation.

(decision support system for agro-technology, a crop simulation model);

- A lack of the required technical understanding and resource personnel to carry out certain analysis, even though the country project members were given adequate capacity building through training and workshops by the experts in the respective fields.

In India analysis was done comprehensively and a similar template was followed in all other partner countries. ICRISAT had in-house technical competencies and could hone a great deal from its long-term data on various variables and hence the report had more reflections and information on India than on other countries.

2.7 Data Sources and Analysis

Both quantitative and qualitative data and related analytical methods were used to understand biophysical inter-linkages and social relationships with reference to drivers of change, i.e. using data available on socio-economic, institutional and political factors (Bryman, 2006).

A detailed micro-level survey was carried out for the identified region highly vulnerable to climate change in these study countries, and a representative sample of farm households in India, Bangladesh, Sri Lanka, China, Thailand and Vietnam (Table 2.3) were surveyed for in-depth analysis. The historical weather data were collected from nearby weather stations and from secondary sources.

Table 2.3. Study countries, villages and number of households sampled.

Country	Province/district	Village chosen for study	Number of households sampled for survey[a]
South Asia			
India	Mahabubnagar	Aurepalle	30
		Dokur	30
	Akola	Kanzara	30
		Kinkheda	30
	Maharashtra /Solapur	Kalman	30
		Shirapur	30
Sri Lanka	Puttalam	Mangalapura	50
	Anuradhapura	Galahitiyagama	60
	Hambanthota	Bata-Atha	50
		Mahagalwewa	50
Bangladesh	Mymensingh	Nishaiganj	30
	Thakurgaon	Boikunthapur	30
	Madaripur	Paschim Bahadurpur	30
	Chaudanga	Khudaikhali	30
South-east Asia			
Thailand	Chok Chai	Don Plai	40
	Nakhon Ratchasima	Kudsawai	40
	Chatturat	Tha Taeng	40
	Chaiyaphum	Nong Muang	40
Vietnam	Phuoc Nam	Vu Bon	80
	Phuoc Dinh	Nho Lam	80
East Asia			
China	Guizhou	Lucheba	30
	Guizhou	Dajiang	30

[a]Surveys done in each village; samples determined based on proportion to size.

Although the respondents' perceptions on essential weather vary, the main focus was on rainfall-related parameters. Respondents were asked how they are changing their crops and enterprises in response to the changes perceived about climate. The changes are noted and the climate was compared with the farmers' perceptions. Further, perceptions of temperature, occurrence of extreme events and associated changes were recalled for recording. In the next stage of analysis, data on crops and cropping patterns, soil- and water-management practices and the reasons for changes in cropping patterns, income structures, expenditure patterns, employment structures, etc., which were related to the possible changes in weather parameters, characteristics of the natural resource base, institutions, policies, etc., in these countries, were analysed. In India, the new information gathered from this study was complemented by available village level longitudinal data as a reference. This data set is a unique longitudinal panel data developed and digitized by ICRISAT and has guided policy analysis on the dynamics of poverty and livelihoods, especially in marginalized and risky environments.

A review of sociological literature on assessment and analysis of past and present adaptation practices and strategies by the poor and vulnerable was undertaken. Supporting policies and infrastructure required for large-scale adoption by the farmers were also assessed using qualitative assessments and social analysis using tools (e.g. Participatory Rural Appraisals, wealth ranking, social mapping, case histories, Venn diagrams, etc.) in order to elicit and document best practices and strategies in adapting to climate change, including mapping institutional arrangements. It helped in eliciting from the respondents their own interpretation of 'why' and 'how' the phenomenon was happening and 'what' were they doing based on their understanding. This qualitative process therefore helped generate explanations regarding the impact and the adaptations, the role of institutions, technology, participation and collective action that were grounded in the context of climate change. On the basis of the results of the analysis, the role of social institutions in adaptation processes and mechanisms to mitigate the effects of climate change were identified. The findings helped to identify not only those who are most vulnerable (in terms of extent as well as magnitude) to climate change and its effects, but also those who can adapt to climate change and how. This learning helped to identify the characteristics as well as the relationships and institutional access people have to deal with the external shocks.

Capitalizing on the existing information base that comprehensively characterizes SAT rural economies (e.g. ICRISAT village-level studies (VLS) (Walker and Ryan, 1990) for India and Bangladesh) have helped in developing and designing long-term investment strategies for poverty reduction. The methodological approaches of the VLS include household and community surveys, which were augmented by the use of meso/macro-level data sets and micro–macro-level modelling (DSSAT and socio-economic models (e.g. IMPACT; Rosegrant *et al*., 2008)), statistical analysis and geographical information system (GIS) tools. The methodology is underpinned by a conceptual framework that appeals to a modified livelihood approach adapted to explain agricultural transformation in SAT Asia.

2.8 Quantitative Assessments

The data for the analysis of climatic characteristics was obtained through various governmental agencies and national research centres (Table 2.4). Weather data analysed are on a daily and monthly basis from 1971–2010. The data period varied among the countries depending upon the data availability. Daily and monthly meso- and micro-level weather data have been collected for the selected locations from the above-mentioned sources. The collected data were examined for quality and averaged (in the case of temperature) or cumulated (in the case of rainfall) to get weekly, monthly, seasonal and annual data. The weathercock, an agro-climatic analysis software program (CRIDA, 2009) was used to obtain the different formats and analysis: rainy days (days

Table 2.4. Data source and reference periods for the selected case studies.

	Climatic data sets[a]		Vulnerability indicators	
Country	Data source	Data period	Data source	Data period
India	Agro-met Data-bank (CRIDA), Indian Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM, Pune)	1971–2010; Daily rainfall and atmospheric temperature data; district (4) and sub-divisional (mandal/tehsil) level of the districts	Meso-level database, ICRISAT, India	1971–2008
Sri Lanka	Sri Lanka Meteorological Department	1976–2008; daily, monthly and annual climatic data for 120 stations	Department of Census and Statistics, Department of Meteorology, Hector Kobbekaduwa Agrarian Research and Training Institute, Report of Labour Force Survey, Coastal Zone Management Plan, Coast Conservation Department, Sri Lanka Statistical Abstract	1977–2007
Bangladesh	Bangladesh Meteorological Department	1971–2008; daily and monthly rainfall data was collected for 27 stations and temperature for 19 locations.	Statistical Yearbook of Bangladesh, Labour Force Survey Reports, Agricultural Sample Survey of Bangladesh and Bangladesh Meteorological Department	1974–2006
Thailand	Thai Meteorological Department	1970–2008; for 120 stations across the country	Land Development Department, Meteorological Department, Royal Forest Department, Office of Agricultural Economics, Royal Irrigation Department, Ministry of Interior, National Statistics Office, National Economic and Social Development Board	2006
Vietnam	Phan Rang Meteorological Station	For Ninh Thuan province Rainfall 1993–2008 Temperature 1993–2008	General Statistical Office, Vietnam	2008
China	Guizhou Weather Bureau and local weather station	1958–2008; data on temperature and rainfall	–	–

[a]Climatic data set period varied among countries depending on availability.

with more than or equal to 2.5 mm rainfall), probability of weekly rainfall for different amounts (Markov Chain probability), meteorological and agricultural drought, extreme weather events (temperature and rainfall), water balance and length of growing period. The non-parametric Mann–Kendall test was performed for identifying the significance in seasonal and annual rainfall and temperature trends over the years using the Trends-Toolkit software. On the basis of the deviation of annual rainfall from its long period average (LPA), meteorological drought has been classified in three categories: 10 to 25% less than LPA – mild drought; 26 to 50% less than LPA – moderate drought; >50% less than LPA – severe drought; accordingly, probabilities of the occurrence of different types of drought have been worked out.

Agricultural drought is defined as a period of four consecutive weeks with rainfall less than 50% of normal during the weeks with normal rainfall of 5 mm or more from mid-May to mid-October (Government of India, 1976). Based on this, the probabilities of occurrence of agricultural droughts were worked out for the selected stations. The trends in length of growing season were analysed on the basis of the Moisture Adequacy Index (MAI). The weekly climatic water balance analysis for the selected stations/locations was worked out using the Moisture Index as per the method of Thornthwaite and Mather (1955) to identify the climatic shift.

2.9 Prioritizing the Target Regions

All study countries are grouped on the basis of the extent of vulnerability, from which regions will be prioritized and focused for an in-depth analysis. How much do regions in these countries differ in terms of vulnerability to climatic-related hazards or change? A vulnerability analysis was undertaken for each of the countries to identify those regions that may be most adversely affected.

2.9.1 Vulnerability

The conditions determined by physical, social, economic and environmental factors or processes give the degree of susceptibility of a community/region to the impact of climatic threats. Vulnerability is the key component in climate change research. This vulnerability assessment is helpful for developing and prioritizing regions of concern and requires efficient channelling of major inputs and development-oriented research and to identify innovative models/strategies meant to reduce vulnerability and to pull regions/districts/countries away from risks.

The majority views vulnerability as a residual of climate change impacts minus adaptations. Here we define vulnerability as the range of changes in degrees and magnitude at which the system is prone to the impact of climatic factors and extreme events. It is also the degree to which the exposure is susceptible to harm due to exposure to a perturbation or stress, and the ability (or lack thereof) of the exposure unit to cope, recover or fundamentally adapt (become a new system or become extinct) (Kasperson *et al*., 2003; O'Brien *et al*., 2004; Malone and Engle, 2011). It can also be considered as the underlying exposure to damaging shocks, perturbation or stress, rather than the probability or projected incidence of those shocks themselves. The main purpose of analysis is to compute vulnerability to climate change of target countries in South and South-east Asian countries. This exercise helped to identify, classify and map the vulnerability in regions/provinces based on a set of multivariate longitudinal data sets.

Vulnerability is a function of the character, magnitude and rate of climate variation. Vulnerability has three components: exposure, sensitivity and adaptive capacity. These three components are described as follows:

1. Exposure can be interpreted as the direct danger (i.e. the stressor) and the nature and extent of changes to a region's climate variables (e.g. temperature, precipitation and extreme weather events). A rise in extreme events such as high temperature and low precipitation will have effects on health and lives as well as associated environmental and economic impacts.

2. Sensitivity describes the human–environmental conditions that can worsen or ameliorate the hazard or trigger an impact.

3. Adaptive capacity represents the potential to implement adaptation measures that help avert potential impacts. There are many opportunities for adaptive capacity, such as better water management in times of drought, early warning systems for extreme events, improved risk management and various insurances.

The first two components together represent the potential impact; adaptive capacity means the extent to which these impacts can be averted. Thus, vulnerability is potential impact (I) minus adaptive capacity (AC). Vulnerability (V) is mathematically represented as:

$$\mathbf{V} = \int (\mathbf{I} - \mathbf{AC}) \tag{2.1}$$

Throughout the world, each country is facing new climatic challenges. Climate changes include higher global temperature, flood, drought, storm and sea level rise. This reviews the climate impacts, vulnerability and adaptation capacity in South and Southeast Asia.

2.10 Vulnerability Analysis

Quantifying vulnerability to the impact of climate change will not be similar in all parts of the region. There will be regional variations where some will be more vulnerable than others. This variability must be captured in order to target interventions in a rational manner. Therefore, vulnerability analysis is undertaken to identify high-risk areas for prioritizing attention by policy makers and programme intervention designers.

A composite index was developed to assess vulnerability and used to rank economic performance of geographic regions. Iyengar and Sudarshan's (1982) method or the IPCC method was adopted to develop a composite index from multivariate data, and it was used to rank the regions/countries/districts in terms of their economic performance. This methodology is statistically sound and well suited for the development of a composite index of vulnerability to climate change. A brief discussion of the methodology is given below.

It is assumed that there are M regions/districts, K indicators of vulnerability and x_{ij}=1,2,..M_{ij}=1,2,...K are the normalized scores. The level or stage of development of i^{th} zone, y_i, is assumed to be a linear sum of x_{ij} as:

$$\bar{y}_i = \sum_{j=1}^{K} w_j\, x_{ij}$$

$$\left(0 < w < 1 \;\; and \;\; \sum_{j=1}^{K} w_j = 1\right) \tag{2.2}$$

are the weights.

In Iyengar and Sudarshan's method the weights are assumed to vary inversely as the variance over the regions in the respective indicators of vulnerability. That is, the weight w_j is determined by:

$$w_j = \frac{c}{\sqrt{(var)x_{ij}}} \tag{2.3}$$

where c is a normalizing constant such that:

$$c = \left[\sum_{j=1}^{j=k} \frac{1}{\sqrt{(var)\,x_{ij}}}\right]^{-1} \tag{2.4}$$

The choice of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution of the rest of the indicators and distort inter-regional comparisons. The vulnerability index so computed lies between 0 and 1, with 1 indicating maximum vulnerability and 0 indicating no vulnerability at all.

For classificatory purposes, a simple ranking of the regions based on the indices, viz. y_i, would be enough. However, for a meaningful characterization of the different stages of vulnerability, suitable fractile classification from an assumed probability distribution is needed. A probability distribution suitable for this purpose is the beta distribution, which is generally skewed and takes values in the interval (0, 1). This distribution has the probability density given by

$$\int(z)=\frac{z^{a-1}(1-z)^{b-1}}{\beta(a,b)},\ 0,\ z,\ 1\ \textit{and}\ \ a,\ b>0. \tag{2.5}$$

where $\beta(a,b)$ is the beta function defined by:

$$\beta(a,b)=\int_0^1 x^{a-1}(1-x)^{b-1}\,dx \tag{2.6}$$

The two parameters 'a' and 'b' of the distribution can be estimated and the beta distribution is skewed. Let $(0,z_1),(z_1,z_2),(z_2,z_3),(z_3,z_4)$ and $(z_{4,}z_1)$ be the linear intervals such that each interval has the same probability weight of 20%. These fractile intervals can be used to characterize the various stages of vulnerability.

1. Less vulnerable if $0<\overline{y}_i<z_1$
2. Moderately vulnerable if $z_1<\overline{y}_i<z_2$
3. Vulnerable if $z_2<\overline{y}_i<z_3$
4. Highly vulnerable if $z_3<\overline{y}_i<z_4$

Indicators and periodic data are specific for the analysis based on availability and completeness. The region considered for computing vulnerability varied with agro-ecological/state/district classification of study country (Table 2.5). For India, a set of 16 indicators was used and 15, 13, 15 and 15 for Thailand, Vietnam, Sri Lanka and Bangladesh, respectively.

2.11 Qualitative Assessments

To capture farmers' perceptions on periodical changes in various biophysical and socio-economy of the rural population and trends in the natural resource base, institutions, policies, etc., surveys were conducted using a detailed and diligently prepared structured questionnaire. The questionnaire had collected information on all key points linked with climate change, agriculture, socio-economic status and trend, collective actions, trends in natural resource base, perceptions and anticipations. In addition, key informant interviews and a focus group discussion (FGD) were conducted to corroborate the information from individual households. Interviews and FGD help attain a comprehensive understanding of the rural set-up and current state of affairs, which supplement household survey information. For India and Bangladesh, long-term panel data were used, which were obtained from a long-term project VLS, mentioned previously. This is a classical study of ICRISAT, initiated in the mid-1970s. Longitudinal household level biophysical and socio-economic data from 1975 onward are available for two different phases, i.e. Generation I (1975–1985) and Generation II (2001–present) (ICRISAT, 2008).

A combination of information gathering tools was used at village level to improve the validity of the FGDs. They included the following: (i) undertaking transect walks; (ii) drawing time lines of key events and village level changes; (iii) undertaking visualized wealth ranking of villagers; (iv) visualizing institutional/actor mapping; (v) resource mapping; and (vi) constructing seasonal calendars. These tools were used by the participating villagers; a manual containing the know-how developed by ICRISAT was used to train the facilitators who used these tools to elicit information from the villagers in all the participating countries.

Social analysis was undertaken to explore, understand and identify various social facets of climate change and variability at the micro-level. The analysis tried to answer critical questions of how farmers are responding to climate change or variability, and also how the individuals or groups who are most vulnerable adapt to effects of climate change. They also helped identify the adaptive capacities. This analysis is expected to provide information on behavioural changes among the households/groups that belong to different socio-economic based strata of rural households in South Asia, South-east Asia and China.

Purposive sampling was used to select farmers to elicit information to understand and identify perceptions of climate change and subsequent adaptation practices. The sample was separated into large, medium and small farmers, landless labourers and women. The objective of the field visits was to understand the perceptions of the farmers in terms of the vulnerability to climate change and their adaptation strategies. Specific focus was also placed on the role of formal and informal institutions in facilitating adaptation practices. The methodology used for data collection was based on FGDs and a semi-structured questionnaire, which was used as an interview guide to probe the incidence of climate change and variability, vulnerability across groups, effects and impacts on agriculture and livelihoods, as well as adaptation mechanisms. The respondents were mainly farmers and other key informants including local elders, teachers and elected officials, and representative groups of women and men who participated in the FGDs.

Because adaptation is local, it is vital to understand the role of local institutions in facilitating improvements in adaptive capacities of the rural poor. Through focus group discussions, youth and women were interviewed to get an insight into the relevance of institutions in the villages, providing adaptive capacities and resilience against vulnerability in general and climate change in particular. To understand how the community had been coping with climatic shocks in the past and what it could do as a future course of action, a mixed group of middle-aged and elderly farmers were interviewed who gave an account of the incidences of a particular climatic shock in a particular year, the effect it had on the village and how the village reacted to cope with the same. The heart of all the focus groups was, however, to understand the perceptions that the community had towards the entire phenomenon of climate change.

2.12 Analysing Economic Impacts

The Ricardian approach is a cross-sectional model applied to agricultural production. It takes into account how variations in climate change affect the net revenue or land value. Following Mendelsohn *et al.* (1994), the approach involves specifying a net productivity function of the form:

$$R = \sum p_i q_i(x, f, z, g) - \sum p_x x \quad (2.7)$$

where R is the net revenue per hectare in the constant rupees, p_i is the market price of crop i, q_i is output of the crop i, x is a vector of purchased inputs (other than land), f is a vector of climate variables, z is a set of abiotic variables, g is a set of economic variables such as market access, literacy, population density, etc., and p_x is a vector of input prices. The farmer is assumed to choose x to maximize the net revenues given the characteristics of the farm and market prices. Assuming a quadratic function for crop output, the standard Ricardian model is specified by the quadratic function:

$$R = \beta_0 + \beta_1 f + \beta_2 f^2 + \beta_5 z + \beta_6 g + u \quad (2.8)$$

where u is an error term and f and f^2 are levels and quadratic terms for temperature and precipitation. The inclusion of quadratic terms for temperature and precipitation ensures non-linear shape of the response function between the net revenues and climate. Normally we expect that farm revenues will have a concave relationship with temperature. When the quadratic term has a positive sign, the net revenue function is U-shaped, but when the quadratic term is negative, the function is hill-shaped. As each crop has an optimal temperature at which it has a maximum growth, the function is expected to have a hill-shape. From the fitted equation, we can find the marginal impact of a climate variable on farm revenue. The marginal impacts are usually found at the mean level of the climate variable. Thus from Eqn 2.8 we have:

Table 2.5. Indicators for computing vulnerability to climate change.[a]

	India (Andhra Pradesh and Maharashtra state)	FR	Thailand (Over all country plus the provinces in the north east)	FR	Vietnam (Country level)	FR	Sri Lanka (25 districts of the country covering all 9 provinces)	FR	Bangladesh (Six ecological zones)	FR
Exposure	Change in rainfall (%)	↑	Change in rainfall (%)	↑	Change in rainfall (%)	↑	Flood and drought (Nos.)	↑	Density of population (sq. km)	↑
	Change in maximum temperature (°C)	↑	Change in maximum temperature (°C)	↑	Change in maximum temperature (°C)	↑	Maximum temperature (°C)	↑	Literacy rate (%)	↓
	Change in minimum temperature (°C)	↑	Change in minimum temperature (°C)	↑	Change in minimum temperature (°C)	↑	Minimum temperature (°C)	↑		
					Change in average temperature (°C)	↑	Rainfall (mm)	↑	Annual rainfall (mm)	↑
Sensitivity	Percentage of cultivable waste	↓	Percentage of irrigated land to agriculture area	↓	Population density (pop/km^2)	↑	Vegetation degradation (%)	↓	Maximum temperature (°C)	↑
	Percentage of gross area irrigated to gross area sown	↓	Total population per unit area (pop/km^2)	↑	Overall poverty (% population)	↑	Total rural population per km^2	↑	Minimum temperature (°C)	↑
	Fertilizer use (t/ha)	↓	Percentage of forest area to land area	↑	Food poverty (% population)	↑	No. of smallholdings	↑		
	Population density (persons/sq. km)	↑	Percentage of paddy land to agricultural land	↑	Km coastal lines/AEZ	↑	Area under major crops (hectares)	↓		
	Percentage of small farmers	↑	Consumption of fertilizer for rice per unit area (kg/ha)	↓			Irrigation intensity of paddy (%)	↓		
	Percentage of Forest area	↓							Area under food crops (Hectares)	↓

continued

Table 2.5. *continued*

	India (Andhra Pradesh and Maharashtra state)	FR	Thailand (Over all country plus the provinces in the north east)	FR	Vietnam (Country level)	FR	Sri Lanka (25 districts of the country covering all 9 provinces)	FR	Bangladesh (Six ecological zones)	FR
Adaptation Capacity	Livestock (no. per ha)	↓	Literacy rate (nos.)	↓	Rice yield (t/ha)	↓	Literacy rate (%)	↓	Cropping intensity (%)	↓
	Percentage of rural agricultural labourers	↓	Average farm size (ha)	↓	Food production (million tonnes/AEZ)	↓	Unemployment rate (%)	↓	Forest area (acres)	↓
	Percentage of cultivators	↓	Percentage of people below poverty line	↑	Animal farm (No. farm/AEZ)	↓	Amount of paddy per hectare	↓	Irrigation intensity (%)	↓
	Percentage of rural literates	↓	Amount of income generated in particular province per capita (Baht)	↓	Percentage forest cover/AEZ area	↓	Number of farms engaged in agriculture	↑		
	Percentage of fodder area	↓	Amount of rice produced per hectare (kg/ha)	↓	No. of enterprise (nos.)	↓	Cropping intensity of paddy (%)	↓	Total employed (nos.)	↓
	Cereals production (tonnes/ha)	↓	Amount of cassava produced per hectare (kg/ha)	↓			Number of cows used for milk production	↓	Total labour force (nos.)	↓
	Pulses production (tonnes/ha)	↓	Gross area comes under cultivation with reference to net area under cultivation (%)	↓					Total self-employed (nos.)	↓
									Total day labourer (nos.)	↓
									Exposed area (sq. km)	↑
									Geographic area (sq. km)	↑

[a]Indicators were selected based on data availability. FR = functional relationship; The functional relationship input for different indicators is based on expert judgment from the respective country. AEZ = agroecological zone. Arrow indicates direction of change (up-arrow signifies increasing pattern, down-arrow signifies decreasing pattern)

$$\frac{\partial R}{\partial f} = \beta_1 + 2\beta_2 \overline{f} \tag{2.9}$$

Where $\overline{f}$ is the mean of the climate variable. This shows that the marginal effect of a particular climate variable is equal to the sum of: (i) the coefficient of the linear term; and (ii) twice the product of the coefficient of the quadratic term multiplied by the mean level of the climate variable. The climate variables included in the model are season temperatures and their squares and season precipitations and their squares. The MATLAB software package was used to fit the model.

2.13 Analysing Impact on Crop Yield using a Crop Model (India and Vietnam)

In India, we used the CMS CERES-Sorghum and CROPGRO-Groundnut models, which are a part of DSSAT v4.5 (Jones *et al*., 2003) to study the impact of climate change factors and CO_2 on the productivity of sorghum and groundnut, respectively. The major components of these models are vegetative and reproductive development, carbon balance, water balance and nitrogen balance. The model needs input of daily weather data (maximum and minimum temperatures, rainfall and solar radiation), crop and cultivar-specific parameters and soil profile data on physical and chemical properties to simulate the growth and development of crops. Growth and development is simulated using daily time step from sowing to maturity and ultimately it predicts yield. The physiological processes that are simulated describe the crop response to major weather factors and soil characteristics determining crop growth. The models also incorporate effects of increase in CO_2 concentration in the atmosphere on growth and yield of these crops by increasing photosynthesis or light-use efficiency and reducing water loss via reduced leaf conductance. Therefore, the effects of changes in temperature, rainfall and CO_2 associated with climate change can be simulated. As the crop models do not incorporate simulation of biotic stresses (pests and diseases) and their effect on crop growth, the model-simulated yields were free from such yield limiting factors. The only factors that the models considered were weather, soil and agronomic management of crops and their interaction on crop growth and yield.

In Vietnam, three categories of models were used to assess climate change impacts on crop production. This includes crop simulation models, hydrologic models and river basin models. For river deltas, hydrodynamic models are applied to evaluate sea level rise effects on inundation and salinity intrusion, which affect the availability of cropland, especially rice land. Crop models simulate crop yields based on growing period weather condition, soil properties, crop genetic characteristics and management. A process-based crop simulation model, WOFOST, and a semi-empirical crop model are conjunctively used. WOFOST (Boogaard *et al*., 1998) is used to simulate potential yields under baseline and climate change scenarios. Relative potential yield changes owing to increases of temperature and atmospheric CO_2 concentration are determined with simulated yields under baseline and climate change scenarios. These relative yield changes are taken by a semi-empirical hydro-crop model that simulates crop yield responses to water deficit, under rainfed and irrigated conditions. For irrigated conditions, the hydro-crop model (Thurlow *et al*., 2009) takes applied irrigation water from the river basin models. For rainfed conditions, rainfall and soil moisture are the water input for crop evapotranspiration.

2.14 Summary and Conclusion

This chapter describes in length the framework of methodology adopted in analysing the components of climate change vulnerability and impacts. The framework included vulnerability analysis using the macro/meso-level analysis, micro-level analysis laced with farmers' perception and social analysis. Predicting impact of future climate on crops using a crop simulation model and the economic impact on future climate on selected crops are considered components of the analytical framework. The authors argue that climate change studies should focus on the different aspects of the analytical framework to provide well-fitted information to recommend regional action in the tropics.

Notes

[1] As indicated in the project proposal, expected benefits from this project include: (i) benefits to the poor sector-marginalized; vulnerable and different social groups will be better informed about climate change, adaptation and mitigation strategies; (ii) economic benefits: improved strategies for managing risk and vulnerabilities are expected to diversify sources of livelihood and alternative coping strategies through institutional innovations; (iii) environmental benefits: new policy, institutional and technological options are expected to lead to improved management of scarce water resources and reduced resource degradations through altered cropping patterns; and (iv) capacity building: improved databases, information and training lead to enhanced capacity for policy research in the national programmes.

[2] This is the ambitious project of linking rivers aimed to reduce the damage of recurrent floods in the north and water shortages in the western and southern part of India. There has, however, been opposition from different groups; currently this project is on hold and concerted studies are being undertaken on assessing ecological, social, economic and environmental feasibility.

[3] Lowest local governance structure in Sri Lanka.

[4] Migration can be classified as: (i) step-up migration where the migrants will be able to improve their livelihoods; (ii) step-down migration where the migrants for various reasons face a more difficult situation of reducing their quality of life due to the conduct of the host location; and (iii) where the migrants do not experience a difference.

[5] The Asian Development Bank supported regional technical assistance project (RETA 5812) to ICRISAT for a project on 'Improving Management of Natural Resources for Sustainable Rainfed Agriculture' in 1999. http://www.icrisat.org/what-we-do/agro-ecosystems/ADB/introduction.htm (Accessed 25 June 2015).

[6] In India, climatic analysis at district level was done for four districts; however, further in-depth micro-level analysis was done for three districts but not for the Anantapur district of Andhra Pradesh state.

References

Adger, W.N. (2003) Social capital, collective action, and adaptation to climate change. *Economic Geography* 79, 387–404.

Adger, W.N. and Vincent, K. (2005) Uncertainty in adaptive capacity. *Geosciences* 337, 399–410.

Adger, W.N., Arnell, N.W. and Tompkins, E.L. (2005) Successful adaptation to climate change across scales. *Global Environmental Change* 15, 75–86.

Aggarwal, P.K., Baethegan, W.E., Cooper, P., Gommes, R., Lee, B., *et al.* (2010) Managing climatic risks to combat land degradation and enhance food security: key information needs. *Procedia Environmental Sciences* 1, 305–312.

Agrawal, A. (2008) *The Role of Local Institutions in Adaptation to Climate Change*. International Forestry Resources and Institutions Program Working Paper 081-3, School of Natural Resources and Environment, University of Michigan.

Below, T.B., Mutabazi, K.D., Kirschke, D., Franke, C., Sieber, S., *et al.* (2012) Can farmers' adaptation to climate change be explained by socio-economic household-level variables? *Global Environmental Change* 22(1), 223–235.

Boogaard, H.L., Van Diepen, C.A., Roetter, R.P., Cabrera, J.M.C.A. and Van Laar, H.H. (1998) *WOFOST 7.1 User's Guide for the WOFOST 7.1 Crop Growth Simulation Model and WOFOST Control Center 1.5*. Alterra, Wageningen, The Netherlands.

Bryman, A. (2006) Integrating qualitative and quantitative research: how is it done? *Qualitative Research* 6(1), 97–113.

Bunce, M., Rosendo, S. and Brown, K. (2010) Perceptions of climate change, multi stressors and livelihoods on marginal African coasts. *Environment, Development and Sustainability* 12, 407–440.

CRIDA (2009) *Manual on Agro-climatic Analysis*. Central Research Institute for Rain-Fed Agriculture, Santosh Nagar, Andhra Pradesh, India.

Government of India (1976) Report of the National Commission on Agriculture on Forest Policy. Ministry of Agriculture, New Delhi.

Hisali, E., Birungi, P. and Buyinza, F. (2011) Adaptation to climate change in Uganda: evidence from micro level data. *Global Environmental Change* 21, 1245–1261.

ICRISAT (2008) *Village Dynamics in South Asia*. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). http://www.icrisat.org/vls-mip/vls_welcome.htm (Accessed 15 July 2015).

Iyengar, N.S. and Sudarshan, P. (1982) A method of classifying regions from multivariate data.

Economic and Political Weekly Special Article, 2048–2052.

Jackson, W.A. (2005) Capabilities, culture and social structure. *Review of Social Economy* 63, 101–124.

Jones, J.W.G., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., *et al*. (2003) The DSSAT cropping system model. European Journal of Agronomy 18, 235–265.

Kasperson, J.X., Kasperson, R.E., Turner, B.L., Hsieh, W. and Schiller, A. (2003) Vulnerability to global environmental change. In: Diekman, A., Dietz, T., Jaeger, C.C. and Rosa, E.A. (eds) *The Human Dimensions of Global Environmental Change*. MIT Press, Cambridge, Massachusetts.

Kelly, P.M., and Adger, W.N. (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47, 325–352.

Malone, E.L. and Engle, N.L. (2011) Evaluating regional vulnerability to climate change: purposes and methods. *WIREs Climate Change* 2, 462–474.

Mendelsohn, R., Nordhaus, W.D. and Shaw, D. (1994) The impact of global warming on agriculture: a Ricardian analysis. *American Economic Review* 84, 753–771.

Mertz, O., Mbow, C., Reenberg, A. and Diouf, A. (2009) Farmers' perceptions of climate change and agricultural strategies in rural Sahel. *Environmental Management* 43, 804–816.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., *et al*. (2004) Mapping vulnerability to multiple stressor: climate change and globalization in India. *Global Environmental Change* 14, 303–313.

Patt, A.G. and Schroter, D. (2008) Perceptions of climate risk in Mozambique: implications for the success of adaptation strategies. *Global Environmental Change* 18, 458–467.

Rosegrant, M.W., Ringler, C., Msangi, S., Suler, T.B., Zhu, T. and Cline, S.A. (2008) *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description*. International Food Policy Research Institute, Washington, DC.

Simeaos, A.F., Kligerman, D.C., Rovere, E.L., Maroun, M.R., Barata, M. and Obermaier, M. (2010) Enhancing adaptive capacity to climate change: the case of smallholder farmers in the Brazilian semi-arid region. *Environmental Science & Policy* 13(8), 801–808.

Stringer, L.C., Dyer, J.C., Reed, M.S., Dougill, A.J., Twyman, C. and Mkwambisi, D. (2009) Adaptations to climate change, drought and desertification: local insights to enhance policy in southern Africa. *Environmental Science & Policy* 12(7), 748–765.

Thomas, D.S.G., Twyman, C., Osbahr, H. and Hewitson, B. (2007) Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change* 83, 301–322.

Thornthwaite, C.S. and Mather, J.R. (1955) *The Water Balance*. Publications in Climatology, No. 1, Vol. VIII. Drexel Institute of Technology, Laboratory of Climatology, Centerton, New Jersey.

Thurlow, J., Zhu, T. and Diao, X. (2009) *The Impact of Climate Variability and Change on Economic Growth and Poverty in Zambia*. IFPRI Discussion Paper 890. International Food Policy Research Institute (IFPRI), Washington, DC. Available at: http://www.ifpri.org/sites/default/files/publications/ifpridp00890.pdf (Accessed 25 June 2015).

Vincent, K. (2007) Uncertainty in adaptive capacity and importance of scale. *Global Environmental Change* 17, 12–24.

Walker, T. and Ryan, J. (1990) *Village and Household Economies in India's Semi-arid Tropics*. Johns Hopkins University Press, Baltimore, Maryland.

Yohe, G. and Tol, R.S.J. (2002) Indicators of social and economic coping capacity: moving toward a working definition of adaptive capacity. *Global Environmental Change* 12, 25–40.

3 What's in Store for Asia: Making Sense of Changes in Climate Trends

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Abstract

This chapter provides a comparative meta-analysis of several global studies on long-term climatic trends, extreme events and their consequences on the important countries in Asia and Africa. Here we argue that climate-related losses are of greater magnitude than, and inventoried less than, the losses due to climatic extremes and natural disasters. It tries to answer questions such as what do the data indicate for the regions? Comparative assessment and regional trends are reported for: (i) the semi-arid tropics of India; (ii) the Mekong river region and north-east region of Vietnam; (iii) the semi-arid north-east region of Thailand; (iv) the drought and flood plains of Bangladesh; and (v) the dry regions of Sri Lanka.

3.1 Introduction

Climate is perceived continuously to be changing all over the world and its adverse impacts have always been a matter of great concern among the farming community and developmental agency. Climate extreme events together with an increase in the rate of change in climatic parameters could affect various livelihood sectors including water, agriculture, human health, tourism, transport, energy, etc. Reducing the vulnerability of the system to climate change by an adaptation and mitigation process through different potential options emphasizes the importance of climatic data analysis. It has been understood that a wide array of adaptation options is available but more extensive adaptation measures are required to reduce vulnerability of an ecosystem to climate change. In the realm of climate change impacts and related unnerving environmental and socio-economic challenges, attempts have been made to protect available valuable natural resources such as land, water and associated biological ecosystems that are being degraded at a faster rate and are threatening food security, especially of developing countries. Impacts of extreme

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weather events and disasters that could cause hunger and susceptibility to disease and poverty would affect the very existence of human life on the Earth's surface. Hence it is important to channel the natural resources to assess the climatic trends that can impose greater impacts on agriculture and its dependent sectors together by influencing the economy of rural population. Analysing current climate trends will certainly be a precursor for the realization of the expected future climate change and variability (CCV), targeting specific sectors/regions and prioritizing research needs in capacitating rural farming communities to cope with the climate risk and associated impacts. Climatic analysis is thus essential to understanding the variability and trends of various/important weather parameters and their impact on agricultural production systems.

3.1.1 Learning from historic climatic analysis

Climate trends are highly related to agricultural production, natural resources and the economic status of the community. Farming in semi-arid tropical (SAT) regions is highly rainfall dependent and any fluctuation in its occurrence with respect to its quantum and duration affects the micro- and macroeconomy of a country. Greater fluctuations in climate can drive the economy backward, pushing down from developing to under developing. Farmers in arid and semi-arid tropics are much more climate sensitive than their counterparts in other agroecological regions of the country. Among the set of climatic parameters, rainfall has been crucial in determining the extent of productivity from agricultural farming. Both excess and deficit rainfall patterns that result in floods and droughts, respectively, hamper the farming output. A good amount of work with respect to rainfall and temperature variability trends in India at the macro-level has already been carried out by various research organizations such as India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM) and Indian Council of Agricultural Research (ICAR). Little information is available, however, at the micro-scale, covering the mandal/blocks level. As variability in a weather parameter is observed at micro-level, it is highly desirable to analyse the micro-level (sub-district) data for a better understanding of the phenomena and to work out suitable strategies to reduce the impacts owing to climate extremes. To arrive at the best results of climatic analysis, it is desirable to have at least weather data sets of a minimum of 20–30 years or even more. There are limitations, however, in obtaining the long-term climatic data at sub-district level and it could be overambitious at village level.

The primary objective of this study is to analyse long-term climatic trends at the sub-district level in the representative study region of SAT India and relate them to agricultural output. Under the objective of impact assessment the probabilities of droughts of different intensities and regions prone to drought have been determined. Similarly the change in crop water demand was also computed. An attempt to summarize future climate factors, such as atmospheric temperature, precipitation and atmospheric carbon dioxide, was carried out and the output was used to run crop simulation models to assess the impacts on production. Per se analyses of studies on the impact of climate change on semi-arid agriculture, and on available natural resources and associated socio-economic implications on rural farming household livelihood in these regions have also been attempted.

3.2 Methodology

The climatic analyses using long-term data sets were carried out for the study countries. The type of data, data source and analysis for these countries are given below.

3.2.1 India

The India Meteorological Department (IMD) (Climatological Normals) has been the primary source for the climatic normal of basic parameters such as maximum temperature, minimum temperature, rainfall, relative humidity (morning and evening), sunshine hours and wind speed for 300 stations spread across the country for the period of 1951–1980. Application programs were developed for computing potential evapotranspiration (PET) using a modified Penman method and a water balance parameters computation using the Thornthwaite and Mather (1955) method. The derived climatic water balance parameter termed the index of moisture adequacy (IMA), defined as the ratio of actual evapotranspiration (AET) of PET, has also been estimated. The map of the length of the growing period derived from climatic water balance computation for the Indian region was collected from the National Bureau of Soil Survey & Land Use Planning (NBSS & LUP) as published (Mandal *et al*., 1999). Thematic maps showing the spatial distribution of maximum and minimum temperature, rainfall and IMA for the SAT Indian region have been prepared by superimposing the geo-referenced maps of the SAT regions over the climatic maps prepared for the whole country earlier at the Central Research Institute for Dryland Agriculture (CRIDA) using the geographic information system (GIS) spatial analysis program.

Long-term climatic parameters were observed from the stations, namely Anantapur, Mahabubnagar, Akola and Solapur in the All India Coordinated Research Project on Agrometeorology (AICRPAM), the study region from AICRPAM unit of CRIDA, Hyderabad. The basic climatic parameters, namely daily maximum and minimum temperatures, and rainfall for the period 1971–2009, were analysed both on an annual and seasonal basis, i.e. winter (January–February), summer or pre-monsoon (March–May), south-west monsoon (June–September), north-east monsoon or post-monsoon (October–December). The weather data sets were subjected to different types of climatic analyses using the Weathercock utility program developed at CRIDA, Hyderabad (CRIDA, 2009). Weekly rainfall data were analysed for initial and conditional probabilities and the probability for consecutive wet and dry weeks. Droughts, including meteorological droughts on annual rainfall departure and agricultural drought based on periods of weeks that received less than 50% of normal rainfall continuously for a period of at least 4 weeks during the south-west monsoon season and their probabilities, were analysed. Climate variability and decadal changes in extreme events in temperature and rainfall were also analysed for the study districts. Thematic maps, figures and tables showing trends and variability of different climatic parameters are produced for better visual interpretations.

3.2.2 Sri Lanka

In Sri Lanka, meteorological data observation was started in 1850, but taking systematic observations was started in 1865. The Department of Meteorology (DOM) was established in 1948 and later in 1951 it obtained the membership in the World Meteorological Organization in 1976. Agricultural meteorological (Agro-met) network was started and presently the Department has 20 meteorological stations representing all the Districts, about 35 agro-met stations and about 350 rainfall stations. These stations are maintained by the Government Departments, private organizations and some estates. Sri Lanka recorded meteorological data from seven (07) meteorological stations (Trincomalee, Puttalam, Kurunegala, Colombo, Nuwara Eliya, Hambantota and Batticaloa) to the Global Climatic Observation Network (GCOS). Meteorological data includes atmospheric pressure, temperature, relative humidity, wind speed and direction, etc., while agro-meteorological data includes sunshine hours, soil temperature, minimum on grass and solar radiation. The Department of Meteorology was able to computerize rainfall, maximum and minimum temperatures from 1861 to date, but three-hourly data are still in the hard copies.

3.2.3 Thailand

This analysis employed secondary data of rainfall and temperature during 1970–2009 collected from 120 meteorological stations maintained by the Thai Meteorological

Department (TMD). For the earlier dates, however, the 1951–1969 data were collected from only 47 and 66 meteorological stations that were distributed throughout the country.

The climatic analysis of the whole country and the north-east region was carried out on the basis of the monthly data. Data were checked for their reliability, after which computation was carried out. The 58-year data were analysed for the six decades, i.e. 1951–1959, 1960–1969, 1970–1979, 1980–1989, 1990–1999 and 2000–2009. Mean and standard deviation were calculated to get the annual, monthly and seasonal output. In order to understand the climate changes and variability throughout the period 1970–2009, the analysis work was devoted to finding out the trends of each climatic parameter. The trend for the rainfall during the study period was conducted on an annual and four-season basis (winter, summer, early rainy and late rainy season).

The two nearest meteorological stations provided the daily weather data for the analysis in the study areas. Data from the Chaiyaphum meteorological station represent the climatic data for the Chatturat district and those from the Chok Chai meteorological station for the Chok Chai district. Daily climatic data during the period of 1970–2009 from both stations were averaged to weekly and analysed in the same way as regional and country level. Deviation from the mean (40 years) was calculated, as well as the initial and conditional rainfall probability and probability for consecutive wet and dry weeks.

PET was calculated according to the modified Penman–Monteith method (Monteith, 1988). Water balance parameters were employed to derive a Moisture Available Index (MAI) suggested by Hargreaves (1972). The length of the growing period was calculated using the backward and forward rainfall accumulation method and displayed spatially.

3.2.4 Vietnam

The Phan Rang Meteorological Station (coordinates of 11° 35'S and 108° 59'E) represents the whole Ninh Thuan province. Therefore, Phan Rang climatic data for the period 1979–2008 have been collected and analysed. As a part of the collection and analysis of secondary weather data, a description of the characteristics of important weather parameters, like rainfall and temperature, and also derived water balance parameters, such as Soil Moisture Index (SMI) and IMA, for the semi-arid region have been computed. Application programs were developed for computing PET using the FAO Penman–Monteith method (Allen *et al*., 1998) and Weathercock (developed by CRIDA, India). The length of the growing period was derived from the climatic water balance computation. Rainfall and temperature trends and decadal rainfall shifts were carried out using standard procedures. Future climatic scenarios for different agroecological zones have been collected.

3.3 Climatic Trends

In climate change studies, it is important to understand the long-term trends and changes in climatic variables. This could be an input in quantifying the impacts at various levels of analysis. Analysing current climatic trends will improve our understanding of future climate change and variability affecting specific sectors/regions. This information will help in prioritizing research needs to increase the capacity of rural farming communities to cope with the risk associated with climate change impacts (Howden *et al*., 2007; Morton, 2007). It is an understood and accepted fact that climate is changing; but the extent to which it is changing in the study areas needs to be clarified. Analysing country level climatic information will provide insights into the trends of a country as a whole, but general characterization fails to represent diverse regional or local climatic conditions. The annual rainfall varied from 600 mm in India to 5000 mm in Bangladesh (Table 3.1). No significant trend was observed in annual rainfall in all these countries in the last 40–50 years. However, an increasing or decreasing trend at a more aggregated (regional) level has been observed. Significant changes in the

Table 3.1. Trends in general climatic characteristics of selected countries in Asia (country level).

Climatic parameters	South Asia			South-east Asia		
	India (SAT)	Sri Lanka	Bangladesh	Thailand	Vietnam	China
Annual rainfall	Rainfall varies from 600 to 1000 mm	Average rainfall is 1861 mm and majority area receives 1000–2000 mm and western part gets >3000 mm	North and south-eastern parts receive high rainfall (3000–5000 mm) and western parts receives low rainfall (<2000 mm)	Country average rainfall is 1555 mm. Most areas receive 1200–1400 mm but eastern and southern parts received >4000 mm	Annual rainfall in Vietnam varied from 700–2400 mm The rainfall has decreased about 2% over the past 50 years (1958–2007)	–
Annual rainfall trend	No significant trend in annual and monsoon rainfall. However, increasing trends in regional pattern in monsoon rainfall in west coast, North Andhra Pradesh and north-west India and declining trend in east Madhya Pradesh, north-east India, parts of Gujarat and Kerala was noticed	No significant decrease in annual rainfall but showing decreasing trend of minimum of 2 mm per year in Jaffna (dry zone) and maximum 17 mm per year in Kegalle (wet zone). However, recent analysis of annual average of rainfall over Sri Lanka decreased by about 7% during the 1961–1990 period compared to the 1931–1960 period	Annual rainfall showed an increasing trend	No significant trend in annual rainfall during the past 40 years. There was significant increasing trend in annual and summer (Feb–Apr) rainfall (p <0.1) but no significant trend in winter, early and late rainy season	Annual rainfall showed declining trend in dry season(Nov.–Apr.) and increasing in wet season (Jul.–Aug.)	No significant trend observed in the past 100 years

Heavy rainfall frequency	Significant rising trend in heavy rainfall events is observed in west coast and north-western peninsula (Maharashtra)	Heavy rainfall and high intense rainfall, recent analysis for the period 1961–2008 shows that one day heavy rainfall increased in the western slope	–	–	Frequent occurrence of heavy rainfall events	Frequency of heavy rainfall is increasing in the Chang Jiang basin and resulting in flooding
Contribution of seasonal rainfall to annual rainfall (%)	70–80% of annual rainfall received during south-west monsoon season (June–Sep) except in Tamil Nadu and south coastal Andhra Pradesh (51%)	60% of the annual rainfall is received from the south-west monsoon and second inter-monsoon periods	80% of the annual rainfall is received during summer (south-west monsoon – June to early October). Remaining 20% from other seasons	42% of annual rainfall is received from late rainy (Aug–Oct) and 36% from early rainy season (May–Jul)	–	–
Annual rainy days and its trend	Annual rainy days vary from 30 to 50 days in major part of SAT region	Annual average number of rainy days in the dry zone is generally less than 100 days. In some parts of Hambantota and Puttalam districts in the dry zone the number of rainy days even go below 60. Number of rainy days in the intermediate zone ranges from 100 to 180 days, whereas it is around 180 days or above in the wet zone districts of Sri Lanka	Increased in recent years (2001–2002) when compared to long-term average (1971–2000)	Average annual rainy days are 128. Rainy days are more (51 days) during late rainy season (Aug–Oct), followed by 49 days in early rainy (May–July)	Number of days with rain significantly increased in the North and reduced in South central coastal and Mekong River Delta	–

continued

Table 3.1. *continued*

Climatic parameters	South Asia			South-east Asia		
	India (SAT)	Sri Lanka	Bangladesh	Thailand	Vietnam	China
Annual temperature trend	Annual mean temperature shows an increasing (0.4°C) trend (1901–2003)	Annual mean temperature increased by 0.2°C during 1951–2006. Both T_{max} and T_{min} shows an increasing trend. Highest rise in T_{min} and T_{max} is in high ranges and coastal areas, respectively	Increasing trends in both T_{max} and T_{min}	Annual mean minimum temperature showed slight increasing trend from the 1970s decade to the 2000s decade. A significant rise in both annual T_{min} and T_{max} ($p=0.01$)	Annual mean temperature is increasing at an average of 0.15°C/decade	Annual mean temperature rose by about 1.1°C in the past 50 years
Seasonal temperature trend	No significant trend in mean temperature during monsoon season. North-east monsoon showed highest increase (0.9°C) followed by winter (0.5°C) and summer (0.4°C) during the period 1901–2003	–	–	Significant rising trend in winter and late rain T_{min} ($p=0.01$) but all the four seasons had significant increasing trend in T_{max} ($p=0.01$)	In some months of summer, temperature increased by 0.1–0.3°C	All seasons showed upward trend during the 1951—2001 period. Warming is significant in spring and autumn, but it is very weak in summer

High temperature frequency	–	Both minimum and maximum ambient temperature has increased. The general warming trend is expected to increase the frequency of extremely hot days	–	–	–	Days with $T_{min} <$ 0°C are decreasing significantly since 1950s. No significant increase trend in days with T_{max} above 35°C. But, some parts of North China showed rising trend
Drought	No long-term trends in the frequencies of extreme droughts or floods during monsoon season. However, frequency of its occurrence has increased	The increased frequency of dry periods and droughts are expected. Consecutive dry days are increasing in dry and intermediate zones in Sri Lanka	–	Only mild drought experienced during the last 40 years (12.5%) with no moderate and severe drought probability	–	Serious drought has been experienced in the North China Plain and north-east China frequently in the past 50 years
Length of growing period (LGP)	Ranges from 70 to 120 days in SAT region	The Yala season is from March to August, including the first inter-monsoon and south-west monsoon, and the Maha season is defined from October to February, which includes the second inter-monsoon and north-east monsoon. With respect to rainfall pattern, year around cultivation is practised	–	From 150 to 180 days	From 110 to 60 days for spring rice, 105 to 140 days for summer rice	

occurrence of extreme events, viz. rainfall and high-temperature events, were observed. Analysis also indicated increased occurrence of droughts and floods during recent years in all the target countries (Agrawala *et al*., 2003).

3.3.1 India

Average annual rainfall in the semi-arid regions of India varies from 600 to 1000 mm. Most of the total annual rainfall (60–70%) is received during the south-west monsoon season (June–September). Annual average rainy days are ranged from 30 to 50 days in the major part of the semi-arid regions of India. All-India monsoon rainfall analysis showed no significant trend. In the west coast region, however, north Andhra Pradesh and north-western India showed increasing trends, whereas a decreasing trend was observed over east Madhya Pradesh, north-east India and parts of Gujarat and Kerala. Significant positive trends were observed in heavy rainfall events in the west coast and north-western part peninsula (Maharashtra) (Goswami *et al*., 2006). A significant increasing trend is observed in annual and seasonal mean temperature, except during the south-west monsoon over India. Annual, post-monsoon, summer and winter season mean temperatures increased by 0.4, 0.9, 0.4 and 0.5°C, respectively. No long-term trend was observed in the frequencies of occurrence of extreme events, namely droughts/floods.

Average annual rainfall over Andhra Pradesh is 941 mm and varies from 500 mm in the Anantapur district to 1200 mm in north-coastal Andhra and northern Telangana regions. In Maharashtra, average rainfall is 1240 mm and it ranges from 600 mm in Ahmednagar district to 3300 mm in Ratnagiri district. Andhra Pradesh receives 68% of the total annual rainfall during the south-west monsoon period and 89% in Maharashtra state. There was no significant trend in annual and seasonal rainfall in both the states except an increasing trend was noticed in annual rainfall of Andhra Pradesh at 5% significant level (96 mm during the 1971–2007 periods). Drought analysis of 140 years rainfall data showed that the probability of occurrence of moderate drought is low in the state of Andhra Pradesh (4%) and high in Maharashtra (8%). Negligible probability is observed in Andhra Pradesh (1%) and no such cases were noted in Maharashtra in the case of severe drought. Length of growing season is lowest (70 days) in the Anantapur region of Andhra Pradesh and 90 days in the southern part of Maharashtra. As it moves away from SAT region, the LGP (length of growing period) increases to a maximum of 180 days (Table 3.2).

The Anantapur and Mahabubnagar districts of Andhra Pradesh, and Akola and Solapur in Maharashtra state are the selected target regions for in-depth analysis in SAT. Average annual rainfall is 573 mm (1973–2010) at Anantapur and the remaining three districts receive between 720 and 790 mm. Variability in annual rainfall is highest in Anantapur (35%) followed by Solapur (31%) and lowest in Mahabubnagar (25%). Of the annual rainfall, 73–86% is received in the south-west monsoon season, which is the main cropping season in three locations, except in Anantapur where about 60% of the annual rainfall is received from the south-west monsoon and 27% from the north-east monsoon period. No significant trend in annual and seasonal rainfall is observed in all the four locations except in Solapur, where in summer rainfall showed an increasing trend at 10 % significant level. Lowest annual rainy days were noticed in Anantapur (34 days) followed by Akola (42 days) and Solapur (44 days). The highest is in Mahabubnagar (52 days).

In all the locations, annual mean maximum and minimum temperatures showed an increasing trend except in Akola, where a declining trend in maximum temperature was observed (0.01°C/year). The highest rise in maximum annual temperature is seen in Anantapur (0.04°C/year), whereas Solapur (0.02°C/year) has the minimum temperature. Meteorological drought analysis indicated that the probability of the occurrence of mild drought is greater in Akola and Solapur (21%), followed by Mahabubnagar (16%) and least in Anantapur (13%). In the case of moderate drought, the highest probability is noticed in Solapur (23%) followed

Table 3.2. Climatic trends in the study districts of India.

Parameters	Andhra Pradesh		Maharashtra	
	Anantapur district	Mahabubnagar district	Akola district	Solapur district
Annual rainfall (mm)	573 (1973–2010)	784 (1971–2010)	791 (1971–2010)	720 (1971–2010)
Annual rainfall trend	NS	NS	NS	NS
Contribution to annual rainfall (%)	SWM, 61; NEM, 27; Summer, 12	SWM, 76; NEM, 15; Winter, 1; Summer, 8	SWM, 86; NEM, 10	SWM, 73; NEM, 17; Winter, 1; Summer, 9
Seasonal rainfall trend	NS	NS	NS	NS only Summer RF increasing (10% level)*
Annual rainy days	34	52	42	44
Seasonal rainy days	SWM, 16; NEM, 8; Winter, 2; Summer, 6	SWM, 40; NEM, 7; Winter, 0; Summer, 5	SWM, 34; NEM, 4; Winter, 1; Summer, 3	SWM, 25; NEM, 7; Summer, 8; Winter, 3
Annual mean temperature (°C)	T_{max}, 34; T_{min}, 21.7	T_{max}, 33.3; T_{min}, 21.8	T_{max}, 34.2; T_{min}, 19.4	T_{max}, 34.0; T_{min}, 20.0
Annual mean temperature trend	T_{max}, increasing (1% level)* (0.038°C/year); T_{min}, increasing (NS) (0.001°C/year)	T_{max}, increasing (5% level)* (0.01°C/year); T_{min}, increasing (1% level)* (0.014°C/year)	T_{max}, decreasing (5% level)* (0.01°C/year); T_{min}, increasing (5% level)* (0.017°C/year);	T_{max}, increasing (1% level)* (0.016°C/year); T_{min}, increasing (5% level)* (0.01°C/year);
Seasonal mean max temperature and trend	SWM, 33.6°C (5% level) increasing (0.032°C/year); NEM, 30.6°C (1% level)* increasing (0.056°C/year); Winter, 32.3ºC (1% level)* increasing (0.058°C/year); Summer, 38.6°C (10% level)* increasing (0.005°C/year)	SWM, 32.2°C (NS) decreasing (0.014°C/year); NEM, 30.7°C (1% level)* increasing (0.047°C/year); Winter, 31.8°C (1% level)* increasing (0.025°C/year); Summer, 38.5°C (NS) increasing (0.005°C/year)	SWM, 33.1°C (NS); NEM, 31.6°C (NS); Winter, 31.1°C (NS); Summer, 40.2°C (10% level)*, decreasing (0.005°C/year)	SWM, 32.9°C (NS); NEM, 31.4°C (10% level)* increasing (0.031°C/year); Winter, 32.3°C (1% level)* increasing (0.025°C); Summer, 39.2°C (5% level)* increasing (0.005°C/year)

continued

Table 3.2. *continued*

	Andhra Pradesh		Maharashtra	
Parameters	Anantapur district	Mahabubnagar district	Akola district	Solapur district
Seasonal mean min temperature and trend	SWM, 23.6°C (NS) decreasing (0.011°C/year); NEM, 19.2°C (NS); Winter, 17.5°C (NS); Summer, 24.3°C (10% level)* increasing (0.02°C/year)	SWM, 23.4°C (1% level)* increasing (0.012°C/year); NEM, 19.1°C (NS); Winter, 18°C (NS); Summer, 24.9°C (1% level)* increasing (0.02°C/year)	SWM, 23.6°C (1% level)* increasing (0.023°C/year); NEM, 14.7°C (NS); Winter, 12.6°C (NS); Summer, 23°C; decreasing (0.02°C/year)	SWM, 22.5°C (1% level)* increasing (0.019°C/year); NEM, 16.8°C (10% level)* increasing (0.001°C/year); Winter, 15.4°C (NS); Summer, 23°C (1% level)* increasing (0.02°C/year)
Meteorological drought probability	Mild, 30%; Moderate, 15%; Severe, 11%	Mild, 16%; Moderate, 16%; Severe, nil	Mild, 44%; Moderate, 13%; Severe, 3%	Mild, 21%; Moderate, 23%; Severe, 3%
Extreme rainfall events	> 25 mm/day, increasing	>25 mm/day, increasing	> 25 mm/day, increasing (especially during SWM period)	>25 mm/day, increasing
Extreme temperature events	T_{max} >40ºC Increasing (5% level)*	No significant trend on high temperature events	Decreasing trend (significant at 1%)* was observed in frequency of occurrence of high temperature > 42°C	Increasing trend (significant at 5%) was observed in frequency of occurrence of high temperature >43°C. Decreasing trend (significant at 5%)* was observed in frequency of occurrence of low temperature 7–10°C
Length of growing period	Start, 35 week; End, 47 week; Period, 13 weeks	Start, 28 week; End, 49 week; Period, 22 weeks	Start, 26 week; End, 51 week; Period, 26 weeks	Start, 29 week; End, 48 week; Period, 20 weeks
Climate type	Arid (no change)	Semi-arid (no change)	Semi-arid (no change)	Semi-arid (no change)

*S = significant; NS = non significant; SWM = south-west monsoon; NEM = north-east monsoon; T_{max} = maximum temperature; T_{min} = minimum temperature.

by Mahabubnagar (16%) and the lowest is in Anantapur (13%) and Akola (13%).

The occurrence of severe drought is, however, approximately once in a 10-year period in Anantapur and with minimum probability in Akola and Solapur (3%). No severe drought was observed in Mahabubnagar. There was no trend in heavy rainfall events (>50 mm/day) in all the locations. Extreme temperature events rose significantly with maximum temperature >40°C at Anantapur in the month of March and > 43°C at Solapur in May.

No significant trend was observed in Mahabubnagar in extreme events both in maximum and minimum temperature. However, a decreasing trend in number of days with >42°C in recent years was noticed in Akola. The length of growing period analysis revealed that the shortest growing season is observed in Anantapur (91 days) < Solapur (148 days) < Mahabubnagar (154 days) and < Akola (182 days). In the case of rainfall, there was no significant change but variability is seen in all four locations. From the above analyses it can be concluded that the rainfall is relatively low in these regions, with high variability in quantum, distribution and onset. Rising temperature is evident with a higher probability of meteorological and agricultural drought occurrence. In recent years, increased variability in distribution and onset of monsoon is observed in targeted regions of SAT India. Among the study districts analysed, Anantapur is the most vulnerable district, with highly variable rainfall, a rise in temperature and increased probability of occurrence of drought, shorter length of growing season and poor water balance.

3.3.2 Sri Lanka

The country's annual average rainfall is 1861 mm. Most areas of the country receive 1000–2000 mm and the western part gets >3000 mm of rainfall. Sri Lanka is divided into three regions based on rainfall: the wet zone (total rainfall >2500 mm), intermediate zone (total rainfall between 1750 and 2500 mm) and dry zone (total rainfall <2500 mm). Among the zones, the dry zone is the most water stress vulnerable region in terms of water scarcity and drought. In Sri Lanka, 60% of the annual rainfall is received from the south-west monsoon (May–September) and the second inter-monsoon (October–November) seasons. Temperature shows an increasing trend. Annual mean temperature has increased by 0.2°C during 1951–2006 and the increase has accelerated in recent years. Highest increase in minimum temperature is observed in high elevations and maximum temperature in the coastal areas.

Angunakolapelessa in Hambantota district and Eluwankulama in Puttalam district from the dry zone were selected for in-depth analysis (Table 3.3). The annual average rainfall is 1136 mm (1977–2008) in Angunakolapelessa and little higher rainfall (1193 mm) is received in Eluwankulama (1976–2008). Though not much difference exists in annual rainfall between the two locations, a difference exists in the seasonal rainfall. Angunakolapelessa received 65% of the annual rainfall from the south-west monsoon (May–September) and second inter-monsoon (October–November) seasons, and the remaining 35% from the north-east and first inter-monsoon periods. But, in Eluwankulama, 45% of the annual rainfall is received from the second inter-monsoon and 23% from the north-east monsoon. Both annual mean maximum and minimum temperatures show an increasing trend in Eluwankulama. In Angunakolapelessa, however, a declining trend was prominent in mean maximum temperature up to 1997 and an increase from 1998 to 2008, and minimum temperature decreased until 1994 and has been rising from 1995 to 2008. Analysis of onset and withdrawal of rainy season indicated that there is no significant difference between these two locations. The probability of occurrence of mild drought is higher in Eluwankulama (24%) than Angunakolapelessa (22%) and moderate drought probability is almost the same in both locations (12–13%). In both the locations no severe drought is noticed. In the agricultural drought probability, in Yala season (March–August) 58–59% probability is seen during 36–42 meteorological weeks in both

Table 3.3. Climatic trends in the targeted province of Sri Lanka.

Parameters	Angunakolapelessa meteorological station (Hambantota district)	Eluwankulama meteorological station (Puttalam district)
Annual rainfall (mm)	1136 (1977–2008)	1193 (1976–2008)
Seasonal rainfall (mm)	First inter-monsoon (March–April), 175; SWM (May–Sep), 359; Second inter-monsoon (Oct–Nov), 373; NEM (Dec–Feb), 229	First inter-monsoon (Mar–Apr), 211; SWM (May–Sep), 180; Second inter-monsoon (Oct–Nov), 537; NEM (Dec–Feb), 265
Contribution to annual rainfall (%)	First inter-monsoon (Mar–Apr), 15; SWM (May–Sep), 32; Second inter-monsoon (Oct–Nov), 33; NEM (Dec–Feb), 20	First inter-monsoon (Mar–Apr), 17; SWM (May–Sep), 15; Second inter-monsoon (Oct–Nov), 45; NEM (Dec–Feb), 23
Annual mean temperature trend	T_{max}, decreasing up to 1997, then rising from 1998–2008; T_{min}, decreasing up to 1994, then rising from 1995–2008	T_{max}, increasing; T_{min}, increasing
Onset and withdrawal of rainy season (week number)	Yala onset, 13; Maha onset, 42; Yala withdrawal, 23; Maha, withdrawal, 5	Yala onset, 13; Maha onset, 41; Yala withdrawal, 23; Maha withdrawal, 4
Meteorological drought probability (%)	Mild, 22; Moderate, 13; Severe, nil	Mild, 24; Moderate, 12; Severe, nil
Agricultural drought probability (%)	Yala 59 (week 36–42); Maha 6 (week 46–51)	Yala 58 (week 36–42); Maha 3 (week 46–51)
Length of growing season (no. of weeks per year)	48–50	48–50
Climate type (IMA – index of moisture adequacy)	IMA = –28.4% (dry sub-humid); IMA is declining within dry sub-humid type (1977–2008)	IMA = –23.3% (dry sub-humid); IMA is declining within dry sub-humid type (1976–2008)

SWM = south-west monsoon; NEM = north-west monsoon; T_{max} = Maximum temperature; T_{min} = Minimum temperature; Yala and Maha are cropping seasons of Sri Lanka.

locations. But in Maha season (September–February), the highest probability (6%) is observed during 46–51 meteorological weeks in Angunakolapelessa and it is 3% in Eluwankulama. The duration of crop growing season is around 48–50 weeks during the season in both the locations, indicating that year-round cultivation is possible in the region. Water balance studies for the period 1976–2008 revealed that both the locations come under dry sub-humid climate and there was declining tendency in moisture index values within the dry sub-humid climate type.

3.3.3 Bangladesh

Annual average rainfall in Bangladesh is 2428 mm received on an average of 106 days. The highest rainfall (3000–5000 mm/year) is received in the north and south-eastern parts of the country, followed by the west central part, which receives the lowest rainfall (<2000 mm/year). The entire western part of the country gets the least amount of rainfall (around 1564–1739 mm) and that includes the drought prone areas. Around 70% of the annual rainfall is received from the south-west monsoon (June to early October), 20% during pre-monsoon season (March–May), and the remaining 10% in the post monsoon (October–November) and winter seasons (December–February). An increasing trend was noticed in annual rainfall and in the rainy days in recent years (2001–2002) when compared to the long-term average (1971–2000). April is the warmest month (33.2°C) and January is the coolest (12.5°C). A warming trend is observed in both annual mean maximum and minimum temperature since 1971. Two zones, viz. flood- and drought-prone zones, were selected for the study.

Nishaiganj (Mymensingh district) and Paschim Bahadurpur (Madaripur district) villages from flood-prone areas and Boikunthpur (Thakurgaon district) and Khudaikhali (Rajshahi district) villages were chosen for the study (Table 3.4). Analysis of annual rainfall and rainy days showed a declining trend in both zones. A declining trend in annual rainfall was observed in

Table 3.4. Climatic trends in the targeted flood- and drought-prone regions of Bangladesh.

	Flood prone		Drought prone	
Parameters	Nishaiganj (Mymensingh district)	Paschim Bahadurpur (Madaripur district)	Boikunthapur (Thakurgaon district)	Kudhaikhali (Rajshahi district)*
Annual rainfall trend	Cyclic pattern since 1971 and declining in the late 1990s	Below normal since 2000	Decreasing since mid-1980s	Cyclic pattern since 1980s
Annual rainy days	106	103	89	86
Rainy days trend	Increasing (2%), comparing 1971–2000 and 2001–2002	Increasing (3%)	Decreasing (27% between 1971–2000 and 2001–2002)	Decreasing (3%)
Seasonal rainy days trend	SWM, increasing (9%); PM, increasing (13%); Winter, increasing (17%); Pre-monsoon, increasing (14%)	SWM, increasing (9%); PM, no change; Winter, increasing (14%); Pre-monsoon, decline (13%)	SWM, decreasing (11%); PM, decreasing (45%); Winter, increasing (17%); Pre-monsoon, decline (43%)	SWM, decreasing (6%); PM, no change; Winter, decline (150%); Pre-monsoon, increasing (9%)
Annual mean temperature	T_{max}: 30.0°C; T_{min}: 20.7°C	T_{max}: 30.9 °C; T_{min}: 21.2 °C	T_{max}: 30.0°C; T_{min}: 19.7°C	T_{max}:31.0°C; T_{min}: 20.5°C
Annual mean temperature trend	T_{max}, increasing (0.2°C); T_{min}, increasing (1.4°C)	T_{max}, declining (0.5°C); T_{min}, increasing (0.4°C)	T_{max}, declining (0.4°C); T_{min}, increasing (1.6°C)	T_{max}, declining (0.2°C); T_{min}, increasing (1.6°C)
Seasonal mean maximum temperature and trend	SWM: 31.6°C (IT – 3°C/year); PM: 31.5°C (DT – 0.3°C/year); Winter: 26.9°C (DT – 0.2°C/year); Summer: 31.6°C (DT – 0.8°C/year)	SWM: 32.0°C (DT – 0.7°C/year); PM: 32.2°C (DT – 0.5°C/year); Winter: 27.6°C (DT – 0.3°C/year); Summer: 33.4°C (DT – 0.9°C/year)	SWM: 32.2°C (DT – 0.1°C/year); PM: 31.1°C (IT – 0.2°C/year); Winter: 26.1°C (DT – 0.5°C/year); Summer: 32.3°C (DT – 0.9°C/year)	SWM: 32.6°C (IT – 0.1°C/year); PM: 31.7°C (DT – 0.1°C/year); Winter: 26.8°C (DT – 0.2°C/year); Summer: 34.4°C (DT – 0.3°C/year)
Seasonal mean minimum temperature and trend	SWM: 25.8°C (IT – 0.9°C/year); PM: 24.4°C (IT – 0.9°C/year); Winter: 14.4°C (IT – 1.8°C/year); Summer: 21.4°C (IT – 1.7°C/year)	SWM: 25.8°C (IT – 0.2°C/year); PM: 24.8°C (IT – 0.2°C/year); Winter: 14.9°C (IT – 0.7°C/year), Summer: 22.4°C (IT – 0.2°C/year)	SWM: 25.7°C (IT – 0.6°C/year); PM: 23.7°C (IT – 1.2°C/year); Winter: 12.8°C (IT – 2.2°C/year); Summer: 20.2°C (IT – 1.8°C/year)	SWM: 26°C (IT – 1.2°C/year); PM: 24.4°C (IT – 0.9°C/year); Winter: 13.7°C (IT – 1.8°C/year); Summer: 21.6°C (IT – 2.3°C/year)

IT = increasing trend; DT = decreasing trend; SWM = south-west monsoon; PM = post-monsoon; T_{max} = maximum temperature; T_{min} = minimum temperature.
*Note: For Khudaikali village, information was taken from the nearest meteorological station, i.e. Rajshahi district.

three villages and a cyclic pattern was noticed in Khudaikhali village since the 1980s. The number of rainy days has increased, however, by 2–3% in these villages of the flood-prone zone during 2001–2002 compared to 1971–2000. Declining trends were observed, however, in Boikunthpur village (27%) and Khudaikhali village (3%). Rainy days during the main rainy season (south-west monsoon) also showed a similar pattern. In the case of annual mean maximum temperature, a declining trend (0.2–0.5°C between 2001–2008 and 1971–2000) was seen in the three villages except Nishaiganj, where an increasing trend (0.2°C between 2001–2008 and 1971–2000) was observed. Annual mean minimum temperature showed an increasing tendency in all four villages. The rate of increase in temperature was higher (1.6°C) in villages of drought-prone areas, whereas in flood-prone villages it varied from 0.4 to 1.4°C.

3.3.4 Thailand

Average annual rainfall of the country is 1564 mm, received in 128 days. Late rainy season (August–October) contributes to around 42% of annual rainfall, followed by 36% from early rainy season (May–July). Annual mean minimum temperature showed marginal increasing trend from 1970 to 2000. In the north-east region the annual rainfall varies from >2400 mm in eastern parts to 1000–1200 mm in western parts and annual average rainy days ranged from 100 to 139. Almost 80% of annual rainfall is received from May to October. Annual mean maximum and minimum temperature over this region ranges from 31.3 to 33°C and 19.7 to 22.5°C, respectively.

Chatturat district of Chaiyaphum province and Chok Chai district of Nakhon Ratchasima province were selected for in-depth analysis (Table 3.5). In this region, rainfall analysis using 39 years of data (1970–2008) indicated that Chok Chai district receives an average annual rainfall of 1087 mm and Chatturat district receives 1115 mm per year. Both these districts get the major share (84–85 %) of annual rainfall from early and late rainy seasons (May–October). Annual and seasonal rainfall showed declining trend in Chok Chai district during 1970–2008, whereas in Chatturat district an increasing tendency is observed except in the early rainy season (May–July) during which a declining tendency was noticed (Kwanyen, 2000; Manton *et al*., 2001; Limsakul *et al*., 2007). Studies on length of growing season revealed that medium duration rice varieties can be cultivated in both the districts as the moisture regime is conducive for 19–21 weeks. In the case of field crops, length of growing season ranges from 25 to 27 weeks in both districts and crops like cotton can be cultivated. The length of growing season is 2 weeks longer in Chok Chai district than Chatturat district for both rice and field crops. This might be due to the Chok Chai district receiving a little higher amount of rainfall during the winter season than Chatturat district.

3.3.5 Vietnam

Vietnam is a tropical country, and is considered one of the five Asian countries most vulnerable to climate change impacts. It was observed that annual rainfall is slightly increased. Nevertheless, an increasing tendency in rainfall was noticed during rainy season and a decreasing trend during dry season (Nguyên, 2007). Annual mean temperature has increased by 0.1°C per decade but it has risen to 0.3°C per decade during certain months.

Ninh Thuan province in the south-east region of the country is a semi-arid tropical area that gets less than 700 mm rainfall per year (Table 3.6). Phan Rang meteorological station, which represents Phuoc Nam commune in Ninh Phuoc district, receives normal annual rainfall of 763 mm (1979–2008). Around 58% annual rainfall is being received during the rainy season (September–November) and the remaining 42% during the dry season (December–August). Annual rainfall showed an increasing trend at 10% probability level for the period 1980–2008

Table 3.5. Climatic trends of study regions in Thailand.

Parameters	Chatturat district (Chaiyaphum province)	Chok Chai district (Nakhon Ratchasima province)
Annual rainfall (mm)	1123.6 (1970–2009)	1084.0 (1970–2009)
Annual rainfall trend	No significant trend	No significant trend
Seasonal rainfall (mm)	Summer (Feb–Apr), 153.1; Early rain (May–July), 404.6; Late rain (Aug–Oct), 540.7; Winter (Nov–Jan), 24.8	Summer (Feb–Apr), 130.4; Early rain (May–July), 388.9; Late rain (Aug–Oct), 526.7; Winter (Nov–Jan), 38.0
Contribution to annual rainfall (%)	Summer (Feb–Apr), 14 ; Early rain (May–July), 36; Late rain (Aug–Oct), 48; Winter (Nov–Jan), 2	Summer (Feb–Apr), 12; Early rain (May–July), 36; Late rain (Aug–Oct), 49; Winter (Nov–Jan), 4
Seasonal rainfall trend	Summer (Feb–Apr), no significant trend; Early rain (May–July), no significant trend; Late rain (Aug–Oct), no significant trend; Winter (Nov–Jan), no significant trend	Summer (Feb–Apr), no significant trend; Early rain (May–July), no significant trend; Late rain (Aug–Oct), no significant trend; Winter (Nov–Jan), no significant trend
Annual rainy days	101	112
Annual rainy day trend	No significant trend	No significant trend
Annual max. and min. temperature (°C)	Average annual $T_{max}=32.7$; Average annual $T_{min}=22.6$	Average annual $T_{max}=32.6$; Average annual $T_{min}=22.2$
Annual max. and min. temperature trend	T_{max} and T_{min} showed significant increasing trend	T_{max} and T_{min} showed significant increasing trend
Seasonal max. and min. temperature (°C)	Winter: average $T_{max}=30.8$; $T_{min}=18.1$ Summer: average $T_{max}=36.3$; $T_{min}=24.7$	Winter: average $T_{max}=30.8$; $T_{min}=17.1$ Summer: average $T_{max}=35.8$; $T_{min}=24.2$
Seasonal max. and min. temperature trend	Winter: T_{max} and T_{min} had significantly increasing trend; Summer: T_{max} had significantly increasing trend but T_{min} had no significant trend; Early rain season: T_{max} had no significant trend but T_{min} showed significantly increasing trend; Late rain season: both T_{max} and T_{min} showed significantly increasing trend	Winter: both T_{max} and T_{min} had significantly increasing trend; Summer: T_{max} had no significant trend but T_{min} had significantly increasing trend; Early rain season: both T_{max} and T_{min} had significantly increasing trend; Late rain season: both T_{max} and T_{min} showed significantly increasing trend

continued

Table 3.5. *continued*

Parameters	Chatturat district (Chaiyaphum province)	Chok Chai district (Nakhon Ratchasima province)
Drought probability	Mild, 23.6%; Moderate, 13.2%; Severe, nil	Mild, 16.2%; Moderate, 5.4%; Severe, nil
Heavy rainfall events (>90.1 mm/day)	No significant trend	No significant trend
Extreme temperature events (days with maximum temperature higher than 40.0°C)	No significant trend	No significant trend
No. of dry spells/year (Dry spell signifies a rainy season period of less than 1 mm of rainfall per day for 15 consecutive days or no rainfall in a day for 7 consecutive days (times/year))	No significant trend	No significant trend
Length of growing period (weeks)	Start: Rice, 21; Field crops, 15; End: Rice, 40; Field crops, 40; Duration: Rice, 19; Field crops, 25	Start: Rice, 19; Field crops, 15; End: Rice, 40; Field crops, 42; Duration: Rice, 21; Field crops, 27

T_{max} = maximum temperature; T_{min} = minimum temperature.

Table 3.6. Climatic trends in the study region of Vietnam.

Parameters	Phan Rang Station (Ninh Phuoc district, Ninh Thuan Province)
Annual rainfall	763 mm (1979–2008)
Annual rainfall trend	Increasing at 10% level of significance (1980–2008)
Seasonal rainfall	Dry season (Dec–Aug), 320 mm; Rainy season (Sep–Nov), 443 mm
Contribution to annual rainfall	Dry season (Dec–Aug), 42%; Rainy season (Sep–Nov), 58%
Annual and seasonal rainy days	Increased but non-significant
Annual and seasonal temperature trend	No significant trend in T_{max} and T_{min} temperature
Drought	Mild, 27%; Moderate, 23%; Severe, nil

T_{max} = maximum temperature; T_{min} = minimum temperature.

and no significant trend in seasonal rainfall. The variation of rainfall pattern showed that extreme events are likely to recur every decade. Conditional probability analysis for wet weeks showed that wet weeks (20 mm rainfall/week) have a 50% probability to last 10 weeks. This means farmers could raise only short-duration rainfed crops during the assured wet period of 10 weeks.

The analysis of the number of rainy days per year indicated that in all seasons except autumn, rainy days showed a rising trend. The trend is insignificant, however. Meteorological drought analysis of the last 30 years revealed that only 50% of years recorded either mild (8 years) or moderate (7 years) drought, indicating that every second year is rainfall deficient, which negatively affects agricultural production. Severe drought never occurred during the study period at this station. A marginal decline in annual mean maximum temperature was observed and minimum temperature showed an increasing tendency from 1993 to 2008. There is no significant trend, however, over the years in maximum and minimum temperature. The crop growing period is short, starting from late August to December.

3.3.6 China

No long-term significant trend is observed in annual rainfall in China during the past 100 years. The annual precipitation trend over different regions in China from 1956 to 2001 showed a decreasing trend in the Yellow River Basin and North China Plain and an increasing trend in the Yangtze Basin, south-east coastal region and most parts of western China. In addition, the frequency of heavy rainfall events increased in the Chang Jiang Basin, causing heavy damage to agricultural crops by flooding.

The climate characteristic of Guizhou province selected for the study falls under the subtropical humid monsoon climate zone. There are four typical seasons in one year; namely spring from March to May, summer from June to July, autumn from September to November and winter from December to February of next year. In most parts of the province, the average temperature is around 15°C. The hottest month is July with a mean temperature of 22–25°C and the coldest month is January with an average temperature of about 3–6°C. In a normal year, the main rainy season is from May to July.

Analysis of surface air temperature shows that annual mean surface air temperature in China increases significantly, and the trends of change reach 0.22°C/decade for the time period of 1951–2001 and 0.08°C/decade during 1905–2001, respectively (Table 3.7). Annual mean temperature has risen by 1.1°C in the past 50 years. Warming is more significant from the early

Table 3.7. Climatic trends in the study regions of China.

Parameters	Dajiang village (Luodian county)	Lucheba village (Pingba county)
Annual rainfall	1150 mm	1279 mm
Annual rainfall trend	Increased by 33 mm (2.9%) between 1959–1968 and 1999–2008	Decreased by 45 mm (–3.6%) between 1959–1968 and 1999–2008
Contribution to annual rainfall	Rainy season (May–Aug) – 67%	
Annual rainy days	150	192
Rainy days trend	Decreased by 22 days (–14.6%) between 1959–1968 and 1999–2008	Decreased by 11 days (–5.7%) between 1959–1968 and 1999–2008
Annual mean temperature	19.7°C (1959–2008)	14.2°C (1959–2008)
Annual mean temperature trend	Increasing; 0.04°C/decade increased during 1959–2008	Increasing; 0.032°C/decade increased during 1958–2008
Seasonal mean temperature	Winter (Dec–Feb), 11.4°C; Spring (Mar–May), 20.6°C; Summer (Jun–Aug), 26.4°C; Autumn (Sep–Nov), 20.3°C	Winter (Dec–Feb), 5.3°C; Spring (Mar–May), 14.7°C; Summer (Jun–Aug), 21.8°C; Autumn (Sep–Nov), 14.9°C
Seasonal mean temperature trend	Winter (Dec–Feb), increasing 0.5°C (1959–2008); Spring (Mar–May), increasing 0.2°C (1959–2008); Summer (Jun–Aug), increasing 0.1°C (1959–2008); Autumn (Sep–Nov), increasing 0.4°C (1959–2008)	Winter (Dec–Feb), increasing 1.1°C (1959–2008); Spring (Mar–May), decreasing 0.2°C (1959–2008); Summer (Jun–Aug), increasing 0.1°C (1959–2008); Autumn (Sep–Nov), increasing 0.4°C (1959–2008)

T_{max} = maximum temperature; T_{min} = minimum temperature.

1980s and the temperature has kept rising steadily. Seasonal mean temperature for almost all seasons in 1951–2001 has been rising over the years. Warming is also significant in spring and autumn, but it is very weak in summer. In addition, cold nights (minimum temperature of less than 0°C) declined significantly since 1950 but no trend was noticed in warm days (days with maximum temperature >35°C). Serious drought years have been experienced in the North Plain and northeast China frequently in the last 50 years in the country.

3.4 Climate Change Projection – From Bad to Worse

In the preceding analysis, we see a marginal change in rainfall and temperature over the past four decades among the six countries studied. Within each country, however, there was evidence that even in the past there was a significant change in some of the regions studied. For example, in Andhra Pradesh state of India, there is evidence of a significant increase in temperature. There is also a reduction in total rainfall but that was not found to be statistically significant. What is more important is to find out what the future holds for these countries and its people in terms of climate change. Here we have relied on the expertise of renowned climate data analysts and forecasters.

The Intergovernmental Panel on Climate Change (IPCC) is the authoritative body entrusted to undertake quantitative global climatic projections. Simulation output from different global climatic models from the IPCC Data Distribution Centre and country reports on projections were the basis for the synthesis. The results showed that atmospheric temperature and associated rainfall variability will continue to rise in the years to come and will

Table 3.8. Climate change projections for Asia (selected Asian countries).

Climatic parameters	South Asia			South-east Asia		
	India	Sri Lanka	Bangladesh	Thailand	Vietnam	China
Rainfall	Andhra Pradesh Annual: 8% (2021–2050); 10% (2071–2100); SWM: 6% (2021–2050); –6% (2071–2100) Maharashtra Annual: 11% (2021–2050); 19% (2071–2100); SWM: 12% (2021–2050); 13% (2071–2100) (Deviation from baseline average)	South-west monsoon rainfall will increase by 173 mm in 2025, 402 mm in 2050 and 1061 mm in 2100 compared to baseline year. North-east monsoon rainfall will increase by 23 mm in 2025, 54 mm in 2050 and 143 mm in 2100 compared to baseline year	Annual rainfall will increase by 3.8% in 2030, 5.6% in 2050 and 9.7% in 2100 compared to baseline year	No clear information is available for the country as a whole but there are positive and negative projections depending on the region	Annual rainfall will increase by 1.6 to 14.6% by 2100 when compared to 1980–1999	Annual rainfall will increase to 611 mm during 2050 when compared to 1950–2000 average of 467 mm

Table 3.8. *continued*

Climatic parameters	South Asia			South-east Asia		
	India	Sri Lanka	Bangladesh	Thailand	Vietnam	China
Temperature (increment °C)	Andhra Pradesh (max) Annual: 1.7 (2021–2050); 3.6 (2071–2100) SWM: 1.5 (2021–2050); 3.8 (2071–2100) Maharashtra Annual: 1.8 (2021–2050); 3.4 (2071–2100) SWM: 1.4 (2021–2050); 3.2 (2071–2100) Andhra Pradesh (min) Annual: 2.1 (2021–2050); 4.5 (2071–2100) SWM: 1.7 (2021–2050); 3.8 (2071–2100) Maharashtra Annual: 2.2 (2021–2050); 4.5 (2071–2100) SWM: 1.5 (2021–2050); 3.4 (2071–2100)	Annual mean temperature will increase by 0.4°C in 2025, 0.9°C in 2050, 1.6°C in 2075 and 2.4°C in 2100 compared to baseline year	Annual mean temperature will increase by 1°C in 2030, 1.4°C in 2050 and 2.4°C in 2100 compared to baseline year	By the middle of the 21st century (2045–2065), average monthly maximum temperature is expected to increase by 3°C–4°C and average monthly minimum temperature is expected to increase by over 4°C throughout the country	At the end of the century (2100), average annual temperature will increase between 1.1–1.9°C and 2.1–3.6°C	Annual mean temperature will increase by 2.6°C in 2050 over the base period average (1950–2000)
Sea level rise (cm)	48 by end of the century	–	30–100 by 2100	–	11.5 to 68 by 2100	–

Sources: India: A1b scenario of HadCM3; NATCOM (2009), INCCA (2010); Sri Lanka: Samarasinghe, Director General of Meteorology, Sri Lanka Meteorological Department; Bangladesh: Agrawala et al., 2003; Thailand: Southeast Asia START Regional Centre, Bangkok, 2010; China: ADB, 2009; Vietnam: ISPONRE, 2009.
SWM = south-west monsoon; NEM = north-east monsoon.

cause major impact on agriculture and other related sectors. The temperature increase will affect crop growth and productivity, thereby reducing yield. The temperature rise will also have negative consequences on physiological characteristics, such as crop duration, fruit setting, chilling requirement, pollination, etc. Agriculture-based livelihoods would face immediate risk of increased crop failure, loss of livestock and fish stocks, increasing water scarcities and production assets. According to the Millennium Ecosystem Assessment Report (WRI, 2005), potential climate change will impact nine other ecosystems, not just cultivation, and that the nature of risk will increase and vary in the future.

Rainfall projections of the study countries are positive and are encouraging for regions where rainfall is already scanty. The distribution of rainfall has to synchronize, however, to maximize the benefit from this increased projection. Atmospheric temperature is expected to rise in all the regions and extreme temperature events could increase in frequency. Between maximum and minimum temperature, minimum temperature rise will be significant over the years. The magnitude of changes in these countries is given in Table 3.8.

The drastic changes in weather could pave the way for increased pest infestation, stunted growth and low yield, adversely affecting rural communities, pushing them to extreme poverty. These populations have constrained capacities to adapt to climate change, particularly marginal groups who have limited resources and little access to power. This will have compounding effects on global food security and employment.

Sadly, this information has been mostly held captive by the scientific, professional and political elite groups, many of whom have been apathetic and non-responsive over the decades to the imminent dangers that large segments of marginalized communities face. Those whose lives are most affected are not privy to this information for various structural and socio-economic reasons. Moreover, institutions closely associated with the well-being and livelihoods of people in rural areas seem to be disjointed, and interventions and programmes are not informed by climate change projections. Thus, a stronger connectivity between the information generated, inferences from climate change, and various state and non-state institutions at different levels, is needed to make meaningful use of relevant information for preventive and mitigatory actions against the impacts of climate change.

3.5 Summary

As an initial step to understand climatic trends, long-term data sets were analysed at various levels (country/regional/district) to ascertain the prevailing trends in these countries. The country-level analysis showed that the annual average temperature is rising significantly in all countries. Even though the majority of countries have not experienced substantial long-term trends (positive or negative) in rainfall, the variability in rainfall and occurrence of extreme events has increased in recent years. Regional-level analysis also followed a similar trend in temperature and rainfall. An exception is seen, however, with a decreasing trend in rainfall and rainy days in the drought- and flood-prone areas of Bangladesh, and the Guizhou province of China. In India, the annual rainfall increased significantly in Andhra Pradesh and no significant trend was found in Maharashtra. Analysis at an even more disaggregated (district) level demonstrated some differences from aggregated level. In the districts, rising trends in temperature and increasing rainfall variability, i.e. change in onset of monsoon, intra-seasonal droughts, flood occurrence, high rainfall events, and higher probability of drought occurrence, etc., are the main features.

In Bangladesh, rainy days showed a decreasing trend in drought-prone regions and an increasing trend in flood-prone regions and, in Vietnam, rainfall increased significantly in Ninh Phuoc district over the years. In general, floods in Bangladesh and Thailand, droughts in India, Sri Lanka and China, and seawater intrusion in Vietnam are some of the distinct climate-related issues of these countries.

This project seeks to identify regions vulnerable to climate change in these targeted countries of South and South-east Asia and China. A comprehensive review of future climatic projections for these countries signalled that impact could be severe in the years to come. In most of these countries, annual rainfall is projected to increase in future; however, its distribution is not clear. Along with rainfall, temperature will rise significantly in the future and successive rises in sea levels threaten countries that have long coastlines.

Assessing climate change vulnerability in agriculture is essential in identifying regions most exposed to its impacts and targets such regions for building resilience against impacts of climate change. To characterize regions based on vulnerability to climate change, a detailed vulnerability analysis was carried out in these target countries. A set of agro-socio-economic indicators was used to classify regions on the basis of their extent of vulnerability. Vulnerability analysis showed that the majority of districts in the Indian semi-arid tropical regions, southern districts of Sri Lanka (Seo *et al*., 2005), major flood- and drought-prone regions of Bangladesh, north-eastern region of Thailand, majority of the districts of Vietnam including the Mekong river delta (a major rice bowl) and arid and semi-arid north-western region of China fall under the category of 'vulnerable to highly vulnerable' to climate change. This analysis ascertains that all the semi-arid marginal regions of the South and South-east Asian countries are highly vulnerable to climate change. There is also local variability within countries; hence there are areas in a country where risks of climate change are high and others where it is low.

References

Agrawala, S., Ota, T., Ahmed, A.U., Smith, J. and Aalst, M.V. (2003) *Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sunderbans*. Organization for Economic Co-operation and Development (OECD), Paris.

Allen, R.G., Pereira, L.S., Rase, D. and Smith, X.M. (1998) *Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements*. Irrigation and Drainage Paper 56. Food and Agricultural Organisation, Rome, Italy.

CRIDA (2009) *Manual on Agro-Climatic Analysis*. Central Research Institute for Rain-Fed Agriculture, Santosh Nagar, Andhra Pradesh, India.

Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanan, M.S. and Xavier, K. (2006) Increasing trend of extreme rain events over India in a warming environmental. *Science* 314, 1442–1445.

Hargreaves, G.H. (1972) The evaluation of water deficiencies. *Age of Change Priorities for Land and Water, Irrigation and Drainage Specialty Conference*, American Society of Civil Engineers. Spokane, Washington, pp. 273–290.

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

INCCA (2010) Indian Network for Climate Change Assessment. Report 2. *Climate Change and India: A 4x4 Assessment – A sectoral and Regional Analysis for 2030s*. Ministry of Environment and Forest, Government of India, p.164.

Kwanyen, B. (2000) Comparative study of rainfall change in the north of Thailand. In: *Proceedings of the International Conference on The Chao Phraya Delta: Historical, Development, Dynamics and Challenges of Thailand Rice Bowl*. December 2000, Kasetsart University, Bangkok.

Limsakul, A., Sangchan, L. and Boonchon, S. (2007) Spatio-temporal changes in total annual rainfall and the annual number of rainy days in Thailand. *Journal of Environmental Research* 29, 1–21.

Mandal, C., Mandal, D.K., Srinivas, C.V., Sehgal, J. and Velayutham, M. (1999) *Soil-climatic Database for Crop Planning in India*. NBSS Bull. 53. NBSS & LUP (ICAR), Nagpur, India.

Manton, M.J., Della-Marta, P.M., Haylock, M.R., Hennessy, K.J., Nicholls, N., *et al.* (2001) Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998. *International Journal of Climatology* 21, 269–284.

Monteith, J.L. (1988) Does transpiration limit the growth of vegetation or vice versa? *Journal of Hydrology* 100, 57–68.

Morton, J. (2007) The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences USA* 104, 19680.

NATCOM (2009) India's National Communication to UNFCCC. *Data Extraction tool for Regional Climate Scenario (PRECIS) for India*. Ministry of Environment and Forests, Government of India.

Nguyễn, N.D. (2007). *Biễn ðôi khí hâu*. [Climate Change] Nhàxuâtbànkhoahckỹthuât, HàNôi, Vietnam.

Seo, S.N.N., Mendelsohn, R. and Munasinghe, M. (2005) Climate change and agriculture in Sri Lanka: a Ricardian valuation. *Environmental and Development Economics* 10, 581–596.

Thornthwaite, C.S. and Mather, J.R. (1955) *The Water Balance*. *Publications in Climatology*, No. 1, Vol. VIII. Drexel Institute of Technology, Laboratory of Climatology, Centerton, New Jersey.

WRI (2005) *Millennium Ecosystem Assessment Report*. World Resource Institute, Washington, DC.

4 Changing Climate – Responding to the Inevitable

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Abstract

This chapter depicts the trends and future predictions of climate, and current changing patterns of climatic parameters particularly temperature, rainfall and extreme events such as drought that are crucial in the semi-arid environment. The trends in extreme events such as droughts, floods, etc., describe the perceptions and aspirations as conceived by the farmers and identifies determinants of adaptation decisions with respect to their livelihood assets, i.e. natural, financial, physical, social and human. This chapter also presents the comprehensive adaptation mapping of households belonging to different asset categories and further discusses, with evidence, the current status and possible trends in these assets contributing to the livelihood of the poor farmers in semi-arid tropics of six countries in Asia (Bangladesh, India, Sri Lanka, Thailand, Vietnam and China).

4.1 Introduction

According to the report from the Intergovernmental Panel for Climate Change (IPCC) there is convincing evidence that climate change is occurring and that it poses important global risks (IPCC, 2007). Since 1900, the global mean temperature has already increased by 0.7°C, which shows the significant changes in atmospheric temperature occurring particularly due to human activities. A global assessment of data since 1970 has shown it is likely that anthropogenic (human induced) warming has had a discernible influence on many physical and biological systems (IPCC, 2001). This chapter particularly examines the topic of assessment of vulnerability, vis-à-vis different approaches and methods to quantify the vulnerability to climate change. Vulnerability is defined by the IPCC (IPCC, 2001) as the degree to which the system is susceptible to, or unable to cope with, adverse effects of stresses including climate extremes and

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variability. Vulnerability is a function of the character, magnitude and rate of change in stresses to which a system is exposed, its sensitivity, and its ability to adaptation or adaptive capacity.

4.1.1 Micro-level information need

Global climate change seems a reality and a major challenge for agricultural production systems. Most policies to address these challenges are based on aggregated/macro-level information, projections and modelled scenarios, which do not offer concrete contexts at micro-levels, such as how dryland farmers respond by adaptation measures. Aggregated information often does not offer inspiring and sufficient lead lines due to information gaps and large uncertainties.

This study attempts to dovetail micro-level contexts with the macro-level contexts so as to downscale the approaches/information by way of focusing on regional and local landscape situations to develop regional policies. With strong evidence from the study, it is imperative to collect, disseminate and consider the collection/gathering of micro-level information as a crucial initial step in formulating climate-sensitive policies with a specific target orientation (MacCarthy *et al.*, 2001). This could be achieved only through institutionalizing an efficient mechanism for collecting, collating and channelling micro-level information especially related to weather/climate indicators to the policy machinery of the country.

4.2 Climate Change Vulnerability of Study Countries

An important element to define priorities for implementing climate risk management actions, inform decisions and establish policy is the assessment of socio-economic vulnerabilities. This analysis is extremely challenging to effectively link them to actual decisions and policies. A set of indicators was used for the analysis of vulnerability and these indicators were selected to cover multi-dimensional aspects of rural vulnerability (Table 4.1).

4.2.1 India

The districts of Andhra Pradesh and Maharashtra (major states of semi-arid tropical (SAT) India) were considered as target regions for a vulnerability index calculation. Analysis was done for these districts on the basis of a given set of indicators and analysis of decadal trend. These districts were grouped under five major categories, viz. less vulnerable, moderately vulnerable, vulnerable, highly vulnerable and very highly vulnerable. The majority of the districts (>60%) in both Andhra Pradesh and Maharashtra fall under the vulnerable to very highly vulnerable category. During these decadal analyses,[1] the degree of vulnerability fluctuated greatly in both states, particularly in Maharashtra, where the number of districts accrued from vulnerable to very highly vulnerable groups.

4.2.2 Sri Lanka

Similar vulnerability was assessed considering all the components contributing to overall vulnerability such as agriculture, climatic, demographic, occupational and geographic. It was clearly evident from the exercise that in 1977 north-eastern districts were categorized as the most vulnerable districts and the north-western districts as the least vulnerable. In 1977, the study districts of Puttalam, Hambantota and Anuradhapura were categorized as very highly vulnerable. In 2007, among the 22 districts analysed only 10 were under the moderately to less moderately vulnerable category and the remaining 12 were vulnerable with varied degree of vulnerability. Considering the trends among the three study districts, Hambantota District was categorized as highly vulnerable in 1982 and it remained the same even in 2007.

Table 4.1. Climate change vulnerability of selected countries of Asia.

South Asia			South-east Asia		
India	Sri Lanka	Bangladesh	Thailand	Vietnam[a]	China
1. Most of the districts of Andhra Pradesh and Maharashtra are categorized as vulnerable, highly vulnerable and very highly vulnerable. 2. The degree of vulnerability of districts varied with time.	1. In the past 25 years there is no significant improvement in the vulnerability status of the study districts of Sri Lanka. Southern districts are identified as moderately to highly vulnerable. 2. The vulnerability ranking fluctuated bi-dimensionally over the years.	1. Most flood-prone and tidal-prone districts are highly vulnerable. 2. Vulnerability of coastal districts has increased over the years.	1. The north-east region of Thailand is highly vulnerable compared to other regions; and these regions are drier than other parts of the country. 2. Twelve provinces in the north-east region fall under vulnerable, highly vulnerable and very highly vulnerable categories.	1. Out of eight agro-ecological zones in the country, five zones are comparatively very highly vulnerable (NWM, RRD, CHR, SER, MRD) and among the other three NCC and SCC are highly vulnerable and the NEM is vulnerable. 2. Mekong River Delta, the major rice bowl, falls into the very highly vulnerable category.	The highly vulnerable arid and semi-arid region of north-west (most parts of eastern Xinjiang, northern Qinghai, Gansu, Ningxia, Shaanxi, western Inner Mongolia); the Tibet-Qinghai plateau; the Karst uplands of southwest China (parts of Guizhou, Sichuan, Chongqing); and densely populated peri-urban coastal zones (IDRC and DFID, 2008)

[a]NWM = North West Mountainous area; RRD = Red River Delta; CHR = Central High Land; SER = South-east Region; MRD = Mekong River Delta; NCC = North Central Coast; SCC = South Central Coast; NEM = North East Mountainous.
Source: http://ehsjournal.org/http:/ehsjournal.org/michael-bittner/climate-change-vulnerability-country-rankings-maplecroft/2010/

4.2.3 Bangladesh

Of the six zones into which the country is divided, the mixed, low-flood and flood zones of Bangladesh observed a substantial reduction in vulnerability status over the years compared to other zones in the country. These changes could be mainly due to significant improvements in the life and livelihood activities across these ecological zones during the period of analysis, with access to better irrigation and agricultural inputs, and flourishing economic activities such as fisheries and poultry that significantly changed much of the rural economic structure. The remaining agroecological zones are gradually moving towards a highly vulnerable status. The incidence of flood in flood-prone regions is recently decreasing but accompanied by increasing incidences of cyclones, salt intrusion in the coastal belts and incidences of drought-like situations in the non-flood-prone zone where many of the river ecosystems are gradually losing their natural flow in the other zones (including non-flood zones) (FAO, 2004).

4.2.4 Thailand

In Thailand, the north-eastern region is the poorest and most vulnerable region to climate change. In the north-eastern region, the eastern provinces have the highest vulnerability index, i.e. Sakon Nakhon and Nakhon Phanom provinces in 2006. Indicators such as fertilizer use, crop yield, irrigated area and cropping intensity are major determinants and they are negatively correlated to vulnerability. A declining vulnerability trend was observed from eastern to western provinces of the north-eastern region. The two selected provinces for in-depth analysis were among the most drought-prone areas of the region.

4.2.5 Vietnam

Vietnam is divided into eight agroecological zones from North to South, based on topography, climate, soil, geology and agronomy as: North East Mountainous Area (NEM); North West Mountainous Area (NWM); Red River Delta (RRD); North Central Coast (NCC); South Central Coast (SCC); Central High Land (CHR); South East Region (SER); and Mekong River Delta (MRD). Total vulnerability index was computed on the basis of the current data sets and climatic parameters (2009). Analysis of aggregated data at regional level showed that five regions (RRD, NWM, SER, CHR and MRD) are most vulnerable compared to other regions. The other two regions that are moderately vulnerable are NCC and SCC. The NEM falls in the vulnerable category. The sea level rise is an important indicator in computing vulnerability, which is not considered in this analysis, especially for the zones bordered with coastal lines.[2]

4.2.6 China

China is the most populous country with a huge geographical area and diverse agroecological zones with regions highly vulnerable to natural disasters, viz. earthquakes, etc. Studies done on China's vulnerability to climate change identify climate change impacts on sea level rise, water availability, agricultural shifts, ecological disruptions and species extinctions, infrastructure at risk from extreme weather events (severity and frequency), and disease patterns, which are the major challenges in the future. The most vulnerable regions are the arid and semi-arid regions of the north-west, which is where the majority of the poor live. The densely populated peri-urban and coastal zones are moderate to highly vulnerable.

4.3 Farmers' Perception on Agriculture and Climate Variability

Recent literature highlighted that climate-related risks are meaningful and their meanings are determined by perceptions influenced by socially embedded beliefs and values (Adger, 2000). Hence decisions regarding risk are based on the way of life or world views of the individual, household or community (Parthasarathy, 2009). Individuals and groups rank risks in terms of their probabilities, their own coping strategies, and the ability and willingness of the state to help them adapt and survive various crises and disasters (Parthasarathy, 2009). The roles of technology, institutions, individual behaviour and social capital are crucial in determining adaptation to a particular situation. Sen (1985) argued that human development and security are possible only if an individual gets his/her due entitlements and in turn nurtures his or her capabilities to build up an adaptive capacity. Farmers have been facing the variability of rainfall and associated uncertainty in their rainfed crop production system from time immemorial. They have been continuously testing new crops and fine tuning their agriculture by practising various adaptation measures. These autonomous adaptation measures are often in response to the real situations, which are not the effect of a single variable. In fact, they are usually complex and few or more factors are combined together, such as variability and uncertainty in rainfall, socio-economic contexts, market complexities or government policies.

Scientists and policy makers have identified climate change as a serious future threat that needs immediate corrective actions (CCAFS, 2010). It is presumed that climate change will bring in increased variability in rainfall, increased temperatures, and more often increased frequency of climate extremes such as droughts and floods across the globe. Because there have been few studies on farmers' perceptions of climate change (Thomas *et al*., 2007; Mertz *et al*., 2009; Bunce *et al*., 2010), this study used a Q^2 approach. Fieldwork focused on four basic questions:

1. How do villagers perceive climate change?
2. How do farmers respond to climate changes or climate variability?
3. Which individuals or groups are most vulnerable?
4. What kind of adaptive capacities do they have that will help build resilience to effects of climate change?

The present study tries to understand farmers' perceptions on various issues relating to agriculture and their adaptation strategies in India, Sri Lanka and Bangladesh from South Asia, Thailand and Vietnam from South-east Asia, and China. All the study villages are from marginal environments and had been experiencing changes in climate (Fig. 4.1 and Table 4.2).

To capture farmers' perception on periodical changes in various biophysical and socio-economic indicators and dynamics of natural resource use and management, institutions and policies, etc., a detailed perception survey through a structured questionnaire was conducted. Representative samples of each group of farmers were drawn from the selected villages and their perceptions were recorded at interviews using the questionnaires. In addition, key informant interviews and focus group discussions (FGD) were conducted to corroborate the information acquired through individual surveys. Transect walks and other qualitative techniques were also used to supplement the information. In the case of India other unique data from the 'Village-level Studies' (VLS) – a classical longitudinal study of ICRISAT initiated in the mid-1970s – were also used for the set of six villages from India to enhance the understanding of the dynamics of agricultural development of the smallholder farmers in the region. The same template of the questionnaire and other methods were used in all the six countries comprising India, Sri Lanka, Bangladesh, Thailand, Vietnam and China.

4.4 General Characteristics of the Study Locations

The selected villages in India belong to different districts of Andhra Pradesh and Maharashtra. These villages were Aurepalle and Dokur (Mahabubnagar district, Andhra

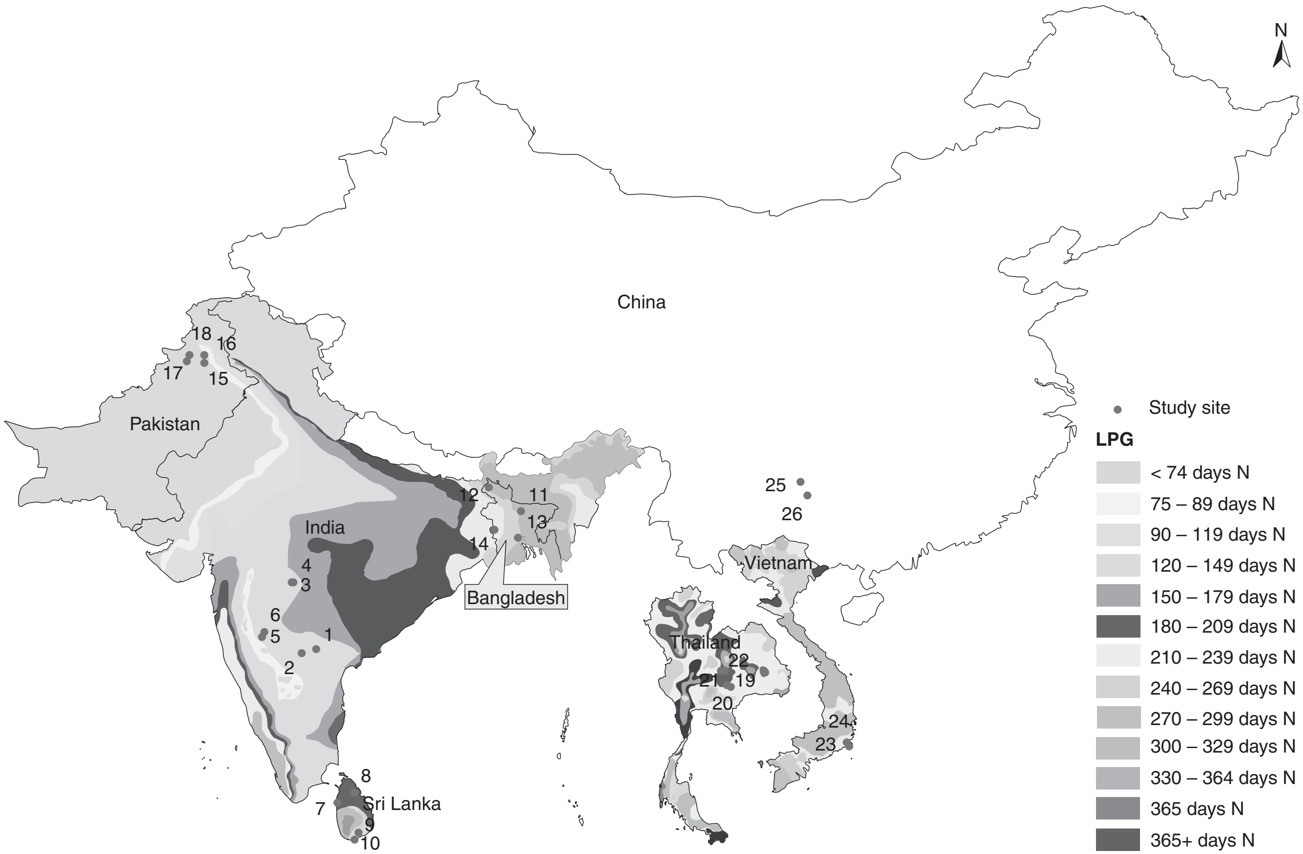

Fig. 4.1. Location of study villages in South Asia, South-east Asia and China. LGP = Length of growing period.

Table 4.2. Location of study villages in South Asia, South-east Asia and China.

S. No.	Country	Province/District	Village	Longitude	Latitude
South Asia					
1	India	Andhra Pradesh/ Mahabubnagar	Aurepalle	78.6	16.9
2	India	Andhra Pradesh/ Mahabubnagar	Dokur	77.9	16.6
3	India	Maharashtra/Akola	Kanzara	77.4	20.7
4	India	Maharashtra/Akola	Kinkheda	77.4	20.6
5	India	Maharashtra/Solapur	Kalman	75.7	17.7
6	India	Maharashtra/Solapur	Shirapur	75.7	17.8
7	Sri Lanka	Puttalam	Mangalapura	79.8	8.0
8	Sri Lanka	Anuradhapura	Galahitiyagama	80.8	8.7
9	Sri Lanka	Hambanthota	Bata-Atha	80.9	6.1
10	Sri Lanka	Hambanthota	Mahagalwewa	81.1	6.4
11	Bangladesh	Mymensingh	Nishaiganj	90.4	24.7
12	Bangladesh	Thakurgaon	Boikunthapur	88.5	26.0
13	Bangladesh	Madaripur	Paschim Bahadurpur	90.2	23.2
14	Bangladesh	Chaudanga	Khudaikhali	88.9	23.6
South-east Asia					
15	Thailand	Chok Chai	Don Plai	102.2	14.7
16	Thailand	Nakhon Ratchasima	Kudsawai	102.2	14.7
17	Thailand	Chatturat	Tha Taeng	101.8	15.6
18	Thailand	Chaiyaphum	Nong Muang	102.0	15.6
19	Vietnam	Phuoc Nam	Vu Bon	108.9	11.5
20	Vietnam	Phuoc Dinh	Nho Lam	109.0	11.4
China					
21	China	Guizhou	Lucheba	106.3	26.4
22	China	Guizhou	Dajiang	106.7	25.6

Pradesh), Kanzara and Kinkheda (Akola district, Maharashtra), and Shirapur and Kalman (Solapur district, Maharashtra). In Sri Lanka, three districts, namely Puttalam, Anuradhapura and Hambantota from the dry zone of Sri Lanka, were chosen for the study. Mangalapura village from Puttalam, Galahitiyagama village from the Anuradhapura district and Mahagalawewa and Bata-Atha villages from the Hambantota district were selected. All these villages represented marginal environments with rainfed agriculture. Khudiakhali village of the Chuadanga district and Boikunthapur village of the Thakurgaon district from the drought-prone zones and Nishaiganj village of Mymensingh district, and Paschim Bahadurpur village of Madaripur district from the flood-prone zones of Bangladesh were chosen to understand how farmers have been adapting to the increasing variability of rainfall. Chok Chai District in Nakhon Ratchasima Province and Chatturat district in Chaiyaphum Province in the north-east region representing dry areas in Thailand were chosen for the study. Don Plai and Kudsawai villages in Chok Chai district are mainly villages with a majority in lowlands and with little irrigation from the Lum Chae Dam, whereas Nong Muang and Tha Taeng villages from Chatturat district are mainly uplands with some irrigated areas from small and medium reservoirs usually getting dry during the dry season. In Vietnam, agricultural production is the important activity, with the engagement of more than 73.41% of population. For this study, we selected Ninh Thuan province, situated in the south-east region along the sea. Ninh Phuoc district was chosen in the Ninh Thuan province because of its predominantly semi-arid nature. In these districts, two communes, Phuoc Nam and Phuoc Dinh were selected and further two villages, one from each commune, namely Vu Bon village from Phuoc Nam commune and Son Hai village from Phuoc Dinh commune, were selected for the study. In China, two counties namely, Pingba County from Central Guizhou and Luodian County from South Guizhou, were selected for the study.

4.5 Dynamic Changes in Cropping Patterns

As seen from the preceding overview of the study villages, there is great variability in the climatic conditions experienced as well as the types of cultivation undertaken by farmers. The level at which villages are integrated to the state will determine to a great extent the level to which the villages can benefit from information generated at the centre and the services presumably designed to benefit the people. A combination of the efficacy of the village-level institutions, the environment, the community dynamics and household capacity will determine how effective the farmers are at making a living. Those who farm the land will adopt cropping patterns that 'best fit' the farmers' farming context.

4.5.1 India

Of the six villages selected, Kanzara is the most prosperous village. Traditionally, Kanzara village is in the cotton-growing belt. Cotton has been grown in the village for centuries. Most of the farmers adopted Bt cotton but soybean has fast replaced cotton after it was introduced in 2005 in the village; about 74% of the area during the kharif season is sown with soybean. Soybean is a cash crop and farmers are getting good remuneration from this crop. In the post-rainy season, wheat and vegetables are the main crops grown under irrigation. Shirapur is the next in rank in terms of prosperity. Traditionally, farmers used to grow pigeonpea, sunflower, pearl millet and sesame in the rainy season, mostly as rainfed crops. With the improvement of irrigation facilities, along with the introduction of canals in 1996, farmers started shifting to cash crops and slowly abandoned food crops. The village now plants over 76% of cropped area with sugarcane. Fodder crops such as maize, grasses and fodder sorghum gained importance of late as the dairy industry started to grow in the village. During the rabi season, farmers usually grow sorghum and wheat. Most of the area was used for sorghum cultivation during rabi in the 1970s and 1980s. Even now, rabi season sorghum is the main crop for most of the farmers in Kalman village.

During the kharif season, pigeonpea was the main crop in the 1970s and it remains a major crop, currently occupying around 66% of the cropped area. In the 1970s, groundnut and pulses such as mungbean and blackgram were common during the rainy season. In recent times, however, the cropped area under pulses and groundnut decreased, whereas that of vegetables and maize increased along with improved irrigation facilities. Rabi is the major season in Kalman and sorghum is the most prevalent crop. Wheat, chickpea and vegetables are also grown under irrigated conditions. Kinkheda comes under the assured rainfall zone. During the 1970s, cotton and cotton-based mixed cropping were dominant; groundnut and sunflower were other commonly grown crops in the village along with sorghum. But groundnut and sunflower almost disappeared in recent times. This is mainly due to wild pig menace. At present, soybean is the dominant crop and more than 50% of the cropped area in kharif is sown with soybean as an intercrop with pigeonpea or soybean as a sole crop. The rapid spread of soybean is because of high prices offered for the produce (market driven), less labour requirement and, most importantly, because it is a shorter duration crop. It is easier to have wheat as a second crop.

Wheat, chickpea and vegetables are the common crops during rabi season in the irrigated areas. Farmers in Aurepalle used to grow sorghum, pearl millet and some pulses in their fields until the 1970s and paddy was grown around the wells. With time, the cropping pattern has changed and now cotton has taken over about 73% of the cropped area in kharif. With the introduction of bore wells, paddy areas have increased and now occupy around 14% of the cropped area. Irrigated paddy cultivation is dominant in rabi season. Groundnut, sunflower and maize are also grown during rabi season in the irrigated areas. Farmers in Dokur used to grow paddy in the irrigated situation; sorghum, groundnut and pigeonpea were grown under the rainfed situation during the rainy season in the 1970s. From 2000, farmers started castor cultivation owing to uncertainty in rainfall and slowly castor cultivation increased with time. At present about 56% of cropped area is with paddy and the second most important crop is castor. Cotton cultivation along with sorghum was reduced with time.

4.5.2 Sri Lanka

Yala and Maha are the two major cultivating seasons in Sri Lanka. Yala season starts in March and ends in August, whereas Maha season starts in September and ends in February. Yala season gets rain from the south-west monsoon and Maha season gets rain from the north-east monsoon.

In Galahitiyagama village, farmers reported that cultivated areas for finger millet, black gram and sesame have decreased over time, whereas those for okra, maize, paddy and other crops (fruits) have increased in Yala season. In Maha season, cultivated area for paddy and foxtail millet has increased, whereas those for chilli, onion, finger millet, green gram, black gram, maize and mustard were reduced. The average yield of chilli, onion, finger millet, maize, okra, groundnut and paddy have increased in Yala season. Average yields of chilli, onion, finger millet and green gram were reduced in Maha season.

In Mangalapura village, most of the farmers are following rainfed farming and irrigation facilities are almost non-existent. During the last four decades, most cultivated area for annual crops have decreased. Farmers were discouraged as yield of most of the annual crops reduced and sometimes crops failed owing to spells of drought. The result is that, during the last few decades, farmers increased the area of perennial crops. In particular, the drought-tolerant species, such as cashew, were favoured by farmers.

In Mahagalwewa village, over the period in the Yala season, cotton cultivation has decreased. Cultivated area for crops such as finger millet, green gram and cowpea has decreased. Paddy cultivation increased from 36% in the 1970s to 41.4% in recent decades. In Maha season, more areas were used to grow crops in recent years, particularly paddy, increasing from 31% to 44% of total area. Cotton cultivation disappeared in recent times from as much as 17% of the area in the 1970s.

In Bata-Atha village, cultivated area of finger millet, green gram, sesame, maize and paddy declined, whereas the area of cowpea and cashew increased in the Yala season. Average yields of chilli, cowpea, groundnut, sesame and tomato declined in the Yala season.

4.5.3 Bangladesh

Drought-prone villages

Rice is the main crop in Boikunthapur village. Almost 76% of the area is under rice cultivation. It usually follows the double-cropping system for Boro and Aman rice. Rice, maize and other vegetables are the major crops. Boro rice cultivation is done by groundwater irrigation, mostly using shallow water pumps, whereas Aman cultivation is rainfed. Farmers used to produce Aus paddy but have now shifted to Boro rice cultivation. Wheat was a popular crop in the village but is slowly being replaced by maize in recent years because it is a longer duration crop. Maize can be produced with fewer water supplies. Demand for maize is increasing day-by-day.

In Khudiakhali, the lowlands are generally used for rice cultivation, whereas betel leaf is increasingly being grown in both low- and semi-high lands (about 40% of the village lands are currently under betel leaf cultivation). Even within rice production, the share of Boro paddy has been increasing and the traditional Aus cultivation has been reduced over the years. Tobacco is also getting popular in recent years. Most of the rice-cultivated lands follow a double-cropping system (Boro and Aman). Along with these, jute, maize and vegetables are also grown in the village. Aus rice, mustard and pulses such as masur (red lentil) and chola (chickpea) are now rarely grown owing to low productivity and less profitability. In Khudiakhali, overall irrigated lands have increased from a mere 11.07% in 1988 to 99.15% in 2004.

Flood-prone villages

Major agricultural activities at Nishaiganj village comprise fisheries and traditional agricultural activities like growing rice, jute and vegetables. Among the most popular crops, rice is the dominant one grown in the lowlands. Farmers follow a double cropping system. Both Boro and Aman rice are grown. Boro rice is dependent on irrigation, mostly groundwater. Jute used to be popular but currently is not commonly grown because of the expansion of other crops and fisheries and lack of water bodies for retting. Vegetables like brinjal, pumpkin, tomato and papaya are also grown. Cereal production is decreasing gradually. During the past 15 years, fisheries have occupied lands suitable for rice cultivation. Jute and cereals have decreased significantly in the village. These changes have been highly facilitated by the availability of inputs and easy marketing facilities, along with the exchange of knowledge about fish cultivation. In Paschim Bahadurpur village, rice is a dominant crop. In addition, farmers produce masur (red lentil), kesari (lathyrus), pea, kalijira (black cumin), dhania (coriander) and vegetables mainly for self-consumption. Aman and Boro rice comprises 90% of total cereal production in the village. Earlier, jute was a prominent crop but from the late 1990s, farmers started to shift to rice and other crops due to the lower profitability of jute. About 40% of farmers in the village are tenants. Pump owners for irrigation generally get one-third of the total produce, whereas the remaining two-thirds are distributed proportionately among owners and tenants. In such a case of a share-cultivation system, input costs are generally borne by all the parties.

4.5.4 Thailand

The average size of the land holdings varied from about 2 ha in the village of Kudsawai to about 4.8 ha in Tha Taeng and 4 ha in Don Plai. Villages Don Plai and Kudsawai have more lowland and villages Nong Muang and Tha Taeng have more upland. In the villages Don Plai and Kudsawai, the area under rice is more than that in villages of Nong Muang and Tha Taeng. Nong Muang and Tha Taeng, being upland villages, have more area under cassava. In the upland village Nong Muang during the 1970s 60% of the area was under rice. But in recent times rice area has reduced from 60% to 31% and the cassava area increased from 30% to 49%. The rest of the area is diversified and is grown to horticultural crops. In village Don Plai, medium- and large-scale farmers diversified into cassava, and now almost all the medium- and large-scale farmers grow this crop. It is the large-scale and medium-scale farmers who are able to take advantage of the energy demand and the associated market advantage of the cassava villages of Thailand. It is interesting to note that roselle (*Hibiscus sabdariffa*) is a crop that yields fibre. It is a water-intensive crop; more particularly, water is needed for extraction of fibre. In the 1970s most of the villages, particularly Kudsawai, Nong Muang and Tha Taeng, were growing this crop but not now.

Upland villages

In village Nong Muang, kenaf/roselle (both species of *Hibiscus* grown for their fibre) used to be a popular crop from the 1970s to 1990s but in recent times most of the farmers gave it up. Particularly the small- and medium-scale farmers stopped growing it. This is mainly because kenaf processing is water intensive and farmers started realizing the importance of water. Similarly in Tha Taeng village kenaf growing stopped in recent decades. Growing cassava increased with time by all categories of the farmers in the village. Almost all the small-, medium- and large-scale farmers grow cassava in parts of their lands in recent times.

4.5.5 Vietnam

In the Phuoc Nam commune, the hybrid maize area reduced with time and was more recently replaced by inbred local maize varieties. Hybrid maize went down to 5% in the area, and inbred maize area increased from 3% to 15%. Rice area decreased from 53% to about 19% owing to lack of sufficient water and uncertain dry spells. Farmers have switched over to neem tree cultivation in a limited way. In the Phuoc Dinh commune, rice area is very small and farmers switched over to aquaculture 20 years ago. Tobacco and legumes occupy a significant area; about 27% of the area is under tobacco and 13% is under legumes. Increase in aquaculture in recent years is seen as an adaptive measure because some of the areas were affected by salt intrusion. Farmers started aquaculture in such areas.

These village studies have provided insights into the present situation with regard to cropping patterns and how they have changed over time. The changes are associated with several factors, including changes in rainfall, availability of markets and prices, as well as new technologies and support systems. These changes include: (i) complete change of crops, i.e. seasonal as well as in some instances perennial or semi-perennial crops, abandoning traditionally cultivated crops; (ii) adopting mixed cropping systems; (iii) increasing cropping intensity; (iv) growing shorter-duration crops; (v) adopting new enterprises such as aquaculture; and (vi) using devices to increase water availability such as water pumps. Depending on the context, agronomic, environmental, and institutional and governance, farmers adopt a range of practices to adapt to situations for sustainable living. Some of these changes can be attributed to climate changes, whereas others are due to other contextual factors and their interactions. Unravelling these relationships requires analysis to identify the factors attributable to the adaptation strategies such as changes in cropping patterns.

4.5.6 China

In Lucheba village there used to be two crops a year in earlier decades. It used to be a rice–oilseed or maize–oilseed cropping system. It gradually changed to three crops a year with the addition of vegetables. The latest trends show that the cropping intensity further increased tremendously. By 2009 about 72% of the area shifted to vegetables and the current year saw the disappearance of all the other crops. At present, farmers can harvest four crops a year of vegetables. In Dajiang village, farmers still grow rice and maize in the rainy season on 26% and 58% of the land, respectively. In about 7% of their land, maize+soybean is grown as mixed crops. This is a good adaptation practice to minimize the risk of yield loss owing to prolonged dry spells. In the dry season about 32% of the area is sown with winter vegetables and this area used to be sown with oilseeds or kept fallow. Farmers are increasing the cropping intensity or switching to more profitable/cash crops such as vegetables.

4.6 Livestock Developments in the Study Location

Farming systems (and adjusting to them) provide opportunities for farmers to adapt to climate-related changes that impact their livelihoods. Although not pervasive in all the study villages in Asia, many benefits are expected from livestock keeping. Livestock raising and management is crucial for an efficient utilization of farm outputs. Mixed crop–livestock systems are increasingly seen as a sustainable and environmentally friendly adaptation strategy that conserves the resources efficiently, maximizes profits and is a promising option for the farmers, especially the resource-poor farmers (Thornton *et al*., 2011). The following sections deal with the livestock situation in the study villages.

4.6.1 India

In all the study villages, the population of local indigenous cows decreased with time. These cattle are low producers of milk. Farmers perceived a decrease in the population of the bullocks, which might be due to increased mechanization of farm activities. In the early 1900s, buffaloes were present in good numbers in the village and, at present, there are around 155 buffaloes here. Over time, the population of buffaloes had decreased, probably due to grazing pressure and poor management of the grazing lands. Farmers also perceived a decrease in the population of goats and an increase in the sheep numbers over this time. Lately, however, the population of buffaloes is increasing because of the improved markets for milk in the village. The farmers in the village are trying to improve milk yield and their income from dairy.

4.6.2 Sri Lanka

In Galahitiyagama village the present survey shows that there are about 185 cows and 140 buffaloes. There are also about 80 goats and 210 poultry in this village. Farmers perceived that there was a major increase in the population of livestock from the 1970s to 2008. Of the studied villages, this is the only village where the livestock population increased with time. The other villages showed a decrease in the population of livestock. In Mangalapura there are about 180 cows and no buffaloes. There are about 37 pigs and poultry numbers crossed 1000. Farmers perceived that there was a major decrease in all these livestock numbers with time, except for the goat population, which saw an increase. Farmers perceived that there was no goat rearing in the past in the village. The scenario is most striking in Bata-Atha village. During the 1970s there were about 2500 cows and 1750 buffaloes in the village. Farmers perceived a drastic reduction in their numbers, and by 2008 there were only 30 cows and 58 buffaloes in the village.

Although farmers were aware about the services such as vaccination, medicines and artificial insemination, the actual service they received was marginal, which could be one of the reasons for the neglect of livestock. Most of the farmers who carried out livestock activities on a limited scale have not used the inputs brought from markets. Whatever was available was fed to the livestock and the livestock was dependent on common grazing sources. Perhaps the absence of milk societies and collection centres and the low demand for milk products may be a reason for arriving at such a situation. Poultry-based activities are also on a very small scale, only for household needs of eggs. Most of the dairy output was for household consumption.

4.6.3 Thailand

Livestock is not a major activity in the study villages in Thailand. Most farmers raise livestock for their household consumption. Occasionally they use them for a little supplementary income. Chicken rearing is the most popular activity among the villages, especially in Don Plai and Nong Muang. Cattle are the second most favoured except in Kudsawai. There are no buffaloes in the study villages. A few swine can be seen in Nong Muang and Tha Taeng villages.

4.6.4 Vietnam

Buffaloes, cattle, goat, sheep, pigs and poultry are commonly found farm animals in Vu Bon and Nho Lam villages. Cattle are the main livestock in Vu Bon village, and sheep in Nho Lam village. There were about 866 cows in Vu Bon and 500 cows in Nho Lam villages. Farmers perceived that there was an increase in all types of livestock in Vu Bon village. The perception in Nho Lam is that except for small ruminants all the other animals increased in number in recent times. Farmers perceived that, due to a shortage of fodder, meat yields of goat and sheep were marginal and they were not profitable. As a result, their numbers decreased. Additionally, during 2007–2008 there was a fall in the prices of sheep and goat in the local markets.

4.6.5 China

Unlike in the case of Thailand, cattle and buffaloes are reared in Lucheba and Dajiang villages for commercial purposes. Buffaloes are used for farm operations such as tillage and so on. Farmers perceived that the buffalo numbers decreased in recent times. This was mainly due to increased mechanization with the introduction of mini tractors and tillers. Farmers perceived that the number of goats increased in the mountainous areas of Dajiang village for the purpose of increasing farm incomes.

Although livestock continue to play an important role in the socio-economic lives of the farmers, the purposes for which they are reared vary significantly. The rearing of large ruminants is dependent on availability of fodder mostly obtained from common grazing land in the localities. Livestock is understood to supplement household income. Mechanization, depleting common grazing land and market prices contribute to the continuity of livestock as an important component of the farm enterprise. In many of the study villages poultry and cattle rearing is done for household consumption. There is evidence that there is a decline in buffalo rearing mainly owing to shrinking grazing land and non-availability of fodder, as well as increased farm mechanization. Clearly, attributing changes in livestock composition in the villages will require analysis of primary data to test correlations.

4.7 Historical Evolution and Current Status of Input Markets

Farmers' adaptive behaviour is closely related to the types of farming practices they adopt. Cropping patterns, livestock rearing and diversifying income sources are general strategies. Changing the crops they grow and livestock they rear will require a complete change in the types of inputs they require and a change in the markets in order to sell their products. A well-functioning and fair market operating at close proximity to the villages will enable them to optimize enterprise restructure provided other requirements are met. Availability of inputs and the distance the farmer has to travel to access these inputs or, in other words, the distance of the input markets as well as the access and availability of output markets are crucial for the farmers to choose the crops that they grow. The following is an analysis of the situation in the study villages, based primarily on farmers' perceptions.

4.7.1 India

Farmers of Aurepalle village perceived that seeds have been available in the village from 1970 onwards. Fertilizer, agrochemical and fodder markets were, however, 10 km away until 1990, but during the last decade all these are available in the village, indicating a major improvement over time. In Dokur, seeds have been available in the village from 1970 onwards. Fertilizer, agrochemical and fodder markets are 7 km away at Devarkadra, the mandal headquarters. In Kanzara village, seeds have not been available in the village from 1970 onwards and the nearest markets are 10 km away. Similarly fodder markets are 10 km away from the village. Fertilizers and agrochemicals were available at around 10 km from the village till the 1990s. During the last decade there was a major improvement and these commodities are now available in the village. In Kinkheda the markets for seeds, fertilizers, agrochemicals and livestock feed are not available in the village. The situation did not change over the years. Seed, fertilizer, agrochemical and fodder markets were 12 km away from the village. In Shirapur village, farmers perceived that important inputs like seeds, fertilizers and agrochemicals are not available in the village. For these inputs farmers used to go to markets that are 12 km away during the 1970s to 1990s. At present new markets have emerged 3 km away from the village. In Kalman village, inputs such as seeds, fertilizers, agrochemicals and cattle feed were available in markets that were 15 km away from the village. There was a major improvement over time and now they are available in the village.

4.7.2 Sri Lanka

Most villages in the vulnerable regions in Sri Lanka are not in the developmental pathway as far as agriculture is concerned. Infrastructure is the key to development of any sector including agriculture. Most of the villages are neglected and even access to seed or seed shops are available in a radius of 10 to 30 km from the village, except in Mahagalawewa, where the seeds are available within the village. Generally, in all four villages, the farmers have to travel outside the village to obtain farming inputs. The situation is the same for inputs such as fertilizers, agrochemicals or cattle feed. Farmers have to face considerable hardships to have access to these inputs and this is probably an impediment to effective adaptation of improved management practices in agriculture.

4.7.3 Thailand

There were no shops in Don Plai village to sell inputs in the 1970s. More recently, three shops opened up in the village that sell all the inputs such as seed, fertilizers and agrochemicals. For cattle feed, the farmers still have to go up to 7 km to buy it. Kudsawai village has a shop selling fertilizers that opened up recently but farmers have to go and buy seed, agrochemicals and cattle feed from some distance away. Farmers in Nong Muang village have to go and buy inputs in the nearby markets that are 9 to 21 km away. In another upland village, Tha Taeng farmers had to travel 15 km to get seed, fertilizers and other inputs during the 1970s to 1990s. Recently the village saw the emergence of shops that sell seed and fertilizers. The situation is still difficult, however, for agrochemicals or cattle feed.

4.8 Development of Output Markets at Micro-level

The availability and accessibility of markets for selling produce is an important factor in achieving maximum returns. It is the availability of the markets that largely influences the farmers' decisions in choosing the specific crop that they grow. The following sections deal with the farmers' perception of the availability and types of transactions that the farmers make regarding their agricultural outputs in the study villages.

4.8.1 India

Farmers in Aurepalle and Dokur villages stated that food grains, pulses and oilseeds were sold in the villages during the 1970s, but with time farmers also started selling in the markets available 10 km away. Food grains and pulses were sold mainly to fellow farmers, whereas oilseeds were sold to local agents. Vegetables were sold in the village till 1990, but during the last decade they also started selling in the nearby market 10 km away. They sold mostly to fellow farmers and local retailers. Milk is sold in the village to retailers. Live animals are sold in the village and nearby market 7–10 km away in both the study villages. They were mostly sold to fellow farmers during the 1970s and in recent times local agents also started buying them. Poultry, eggs and forest produce are sold in the village mostly to local farmers and retailers. In general, markets do exist both in the village and at a distance of 10 km away from the village.

In Kanzara, Kinkheda, Shirapur and Kalman, farmers perceived that food grains, pulses and oilseeds were sold in the village and nearby markets 10–15 km away from the 1970s until now. Food grains and pulses were sold mainly to fellow farmers, whereas oilseeds were sold to local agents. Other agricultural commodities are sold in the village and nearby markets, which are 10–12 km away. They sold these commodities to local agents and retailers. In earlier periods they sold the milk at a distance of 10–12 km from the village but since the 1990s they sell the milk in the village to retailers. Live animals are sold in the village and in a nearby market 10–12 km away. They were mostly sold to fellow farmers during the 1970s and in recent times local agents also started buying the produce. Poultry, eggs and non-timber forest produce are sold in the village mostly to local farmers and retailers, and recently local agents have also started buying the forest produce. In general, markets are located 10–12 km away from the village.

4.8.2 Sri Lanka

In Galahitiyagama, during the 1970s, farmers travelled up to 20 km to sell their outputs. During the 1990s oilseeds and vegetables were sold in the village itself. In recent times almost all the outputs of the farmers are sold in the village. This is mainly due to the arrival of the wholesalers in the village and agents also are active in buying the outputs from the farmers. In Mangalapura village during the 1970s most of the outputs were sold 30 km away in Puttalam town by the farmers and in recent times wholesalers have been appearing in the village to buy the outputs from the farmers. In Mahagalawewa the situation has not changed much since the 1970s. Most of the outputs of the farmers are sold at a distance of 10 km from the village even now, except for poultry and dairy products. The situation is the same in Bata-Atha village. Dairy and poultry products were sold by the farmers in the village but most of the other outputs like cereals, pulses, oilseeds and other agricultural commodities are sold at a distance of 10 km from the village. In general, in most of the villages the farmers have to travel away from the village to a distance of 10 to 30 km to sell their produce. Infrastructure for output markets is not well developed even in recent times. Well-developed infrastructure will help the farmers to plan their strategies of crop production in advance because it reduces the risk and uncertainty of marketing.

4.8.3 Thailand

Rice is sold in the village itself to the mills in recent times, cassava is sold at a distance of 25 km in Don Plai village and sugarcane is sold at a distance of 40 km to the sugar factories. In Kudsawai, rice and cassava are sold at a distance of 3–28 km from the village by the farmers to mills and wholesalers. In Nong Muang, rice is sold at a distance of 2 to 21 km from the village and cassava was sold at a distance of 21 km from the village during the 1970s to 1990s, and in recent times cassava is sold at a distance of 7 km where mills have arisen. In Tha Taeng, rice is being sold at a distance of 15 km and cassava is being sold at distance of 20 km from the village. Sugarcane is being sold at a distance of 60 km from the village to a sugar factory. Most of the other products are sold at a distance of 15 km. Kudsawai and Tha Taeng villages are mostly rainfed and upland in nature and markets are also not developed well around these villages so farmers often have to travel 15–20 km to sell their products.

The means to dispose of produce at a reasonable price at close proximity to the farm is a great advantage and helps to minimize transport and storage costs for farmers. With income enhancement it is probable that the adaptive capacity will improve. The availability of markets at close proximity and the relationship between incomes and ability to adapt to climate change is for the most part a complex causal relationship. The qualitative analysis clearly indicates the benefits of markets being at the ‘doorstep’ as opposed to being far away. The availability of local markets greatly enhances the income-earning capacities, thereby helping to mitigate climate shocks.

4.9 Farm Income – Tracking Diversification at Micro-level

Occupation diversification is closely related to income diversity. It was observed that, in the study villages in India and Sri Lanka, there is considerable diversity of sources of incomes. The diversity of occupations and sources of income are closely associated with market penetration and the presence of various state institutions. In the South Asian countries the situation is similar, especially in India and Sri Lanka, whereas in Thailand and China the income sources are fewer while agriculture remains the main source of income. Diversifying the sources of income indicates a reduction in risk and vulnerability.

4.9.1 India

It is important to understand the income sources/portfolio of the farmers to appreciate the measures that farmers adopt in response to the ground situation. The proportion of income from agriculture in the income portfolio of the farmers remains important. During the past four decades farmers have diversified their incomes into non-farm sources to reduce their exposure to the risk of climatic uncertainties. In Aurepalle it came down from 59 to 42%. In Dokur the share of agriculture in the income portfolio is the lowest and is only 28% at present. The story of Dokur village in Mahabubnagar district of Andhra Pradesh is a case of natural resource degradation. During the 1970s farmers derived 96% of their income from agriculture and by 2007 the contribution of agriculture came down to as low as 28%. Income from non-farm sources in this village increased from just 3% in the 1970s to as high as 58% in 2007. This increased dependence on non-farm sources is mainly due to increased variability in rainfall and associated yield losses.

Most of the natural resources such as groundwater were over-exploited for a decade in the 1990s and the result was the drying up of common resources like tanks and ponds as well as dug wells. These developments drove the farmers towards adaptation measures such as going for the non-farm sources of income such as petty part-time business, salaried incomes, non-farm labour earnings, etc. (Fig. 4.2).

4.9.2 Sri Lanka

Farmers perceived that the proportion of income from cereal-based farming in their agricultural income had increased with time. During the 1970s vegetable cultivation had a share of 45% in the total agricultural income and in recent times it has decreased to 16.9%. This is mainly due to reduced irrigation sources and the fact that the village tanks, which were a source of supplementary irrigation, are drying up frequently owing to insufficient runoffs. In recent times farmers have diversified their incomes into non-farm sectors and business, and outward migration and earnings from service are the major sources of diversification. Recently, income diversification has reduced the risk of rainfall variability through reduced dependence on agricultural incomes. This is seen as an effective adaptation measure by the farmers.

4.9.3 Thailand

Farmers have responded to the circumstances and diversified and changed their income sources over time. Depending on the resource availability, different groups of farmers responded and adapted differently. In the lowland village of Don Plai, landless farmers used to earn more than 97% of their income from cattle farming during the 1970s. In recent times they completely abandoned cattle rearing and started cultivating rice as tenants. Similarly smallholder farmers were also relying heavily on cattle from the 1970s to 1990s but in recent decades their incomes are mostly derived from rice and vegetable cultivation. For the medium- and large-scale farmers the situation was similar during the 1970s but in recent decades their major share of income

Fig. 4.2. Diversifying occupation into non-farm labour to reduce the risk of uncertainty in farm income. (Kinkheda village in Maharashtra, India).

stems from cassava cultivation followed by rice. In another lowland village, Kudsawai, the landless farmers were not dependent on cattle during the 1970s. But in recent times most of the farmers have diversified into incomes from cassava and rice growing, whereas large-scale and medium-scale farmers derive a small part of their income from poultry. Most of their agricultural income arises from cassava and rice. In the upland village of Nong Muang large-scale farmers diversified incomes into cassava and rice and in recent times derive 20% from cassava and 11% from rice. About 50% of their income comes from cattle. And medium-scale farmers derive 38% and 36% from cassava and rice, respectively, and about 22% from cattle. In another upland village, Tha Taeng, cattle is not a prominent income source but in recent times medium- and large-scale farmers derive some income from it. Large-scale farmers derive 71% of their incomes from vegetable cultivation and medium-scale farmers get about 21% of their income from vegetables. Cassava gives 12 and 24% of the incomes for large- and medium-scale farmers. In general incomes from rice form a major share in the lowland villages and other crops like cassava form a major share in the upland villages. Farmers in all the villages diversified their agricultural income in recent times.

4.9.4 Vietnam

Farmers in rainfed areas in Vietnam diversified their income sources. The share of income from crop production increased from 10% during the 1990s to about 22% in recent times. This income mainly came from the cultivation of the food crops, cotton, grapes and other crops. Income from livestock activities from cattle and poultry increased rapidly from 26% in the 1990s to about 61% more recently. In recent times, 18% of the income came from salaried service and other non-farm sources. In general, income diversification is seen among the farmers as a measure to reduce the risk of uncertainty in rainfall on agriculture. The data confirmed the presence of a trend in crop diversification from traditional food crops to more high-value crops, viz. grapes, cotton, vegetables, etc.

4.9.5 China

Out-migration and changing of work place is not possible in China because the population has to register at a place for their work. During the period of the past 20 years, the share of income from farm agriculture has remained more or less the same in Lucheba village but the fraction of income that came from livestock decreased from 36.4% 20 years ago to about 17% in recent times. Off-farm income increased its share from 9% 20 years ago to about 31% in recent years. In Dajiang village the share of income from agriculture decreased from 46% to 35.5% in the last 20 years. Similarly, income from the share of livestock decreased from 48% to 36% and off-farm income increased from just 6% to about 29% in the last 20 years. In general, income diversification among the farmers of marginal areas in China took place with an increased share coming from non-farm income.

4.10 Land Management Practices

Soil management practices that improve the water-holding capacity of the soil and conserve soil moisture are important adaptation measures against variability in rainfall in rainfed agriculture. Practices such as organic matter incorporation through green manure, composting, as well as incorporating crop residues and mulching will improve soil properties and serve as moisture-conserving measures.

4.10.1 India

Several soil management measures to conserve moisture and improve soil quality were listed and discussed with the farmers to understand their perceptions and adaptation status of these measures. More than 30% of the farmers in the village used green manure and incorporated crop residues in the soil during the early period but there is a major decrease in the practice during recent years. Similarly composting was followed by more than 70% of the farmers during the early period from 1970 to 1990 but there is a major decrease in the farmers using compost and only a little above 20% of the farmers are using compost now. Farmers in the village are aware of conservation tillage but very few farmers practice it. Keeping the land fallow was practised by more than 20% of the farmers earlier but in recent times very few people leave the land fallow for one season. Minimal tillage is practised by about 18% of the farmers. One of the major factors that emerges out of this information is that organic inputs to the soil reduced over the years and this is adversely affecting the soil and subsequently this will lead to unsustainable productivity growth.

4.10.2 Sri Lanka

In Galahitiyagama, the practice of mulching, use of green manure, composting, incorporating crop residues in soil, conservation tillage practices and drainage channels have increased during the period of study. The majority of the farmers said that they are practising bunding of their fields. According to the majority of respondents, awareness on all the practices has increased from 1970 to 2008. In Mangalapura, farmers perceived that among the land management practices, mulching, use of green manure, composting and incorporating crop residue, and to some extent bunding their fields, saw a minor increase during the period from 1970 to 2008. Other practices were not common with the farmers. In Mahagalwewa, mulching, use of green manure, composting, bunding and drainage channels saw a minor

Fig. 4.3. A typical unprotected irrigation water supply well dug by a farmer at Mangalapura, Puttalam District, Sri Lanka.

increase during the period 2007–2008. Similar trends were seen in Bata-Atha village (Fig. 4.3).

4.10.3 Thailand

Farmers in upland villages, particularly those with the least possibility of irrigation, as seen in Tha Taeng village, are increasingly adapting organic matter incorporation measures in recent decades as compared to the 1970s. More than 60% of farmers are practising these measures. In the lowland villages, due to the land position, moisture gets accumulated in the rainy season and more often standing water also accumulates in these soils. In villages that have predominantly lowlands, farmers seem to prefer methods that will store the rainwater in their fields. This can be seen by the fact that 80% and 67% of the farmers in Don Plai and Kudsawai villages practised bunding in the past few decades. Incorporating crop residues is followed by about 42% and 31% of the farmers in Don Plai and Kudsawai villages, respectively, in recent decades. Farmers perceived that only 19% and 18% of the farmers, respectively, followed this during the 1970s. In Don Plai village, composting practice increased from 26% during the 1970s to 42% in recent decades. In comparison, all these practices are followed by a higher number of farmers in the upland villages of Nong Muang and Tha Taeng.

Among the sample villages studied, a range of practices in land management was observed as adaptation strategies to the low or uncertain availability of water for agricultural purposes. The practices varied owing to the level of dependency on rainfall and the types of practices adopted reflecting in the differences of farmer experiential knowledge, access to information and penetration of scientific/technical knowledge to the villages.

4.11 Farmers' Perception of Climate Variability

Farmers have been devising and practising various adaptation measures in response to adverse and unpredictable climatic variability such as erratic rainfall, as well as moderate and severe droughts and several other socio-economic shocks such as market movements or absence of supportive institutions. The following section deals with the farmers' perception of climatic variability during the past four decades. Farmers' knowledge of the environment is based on individual as well as their collective experiences. Gathered through the household surveys and FGDs, as perceptions, this information is the basis on which they will decide their adaptation strategies to short-term weather situations and long-term climate change.

4.11.1 India

Farmers in all the villages had similar perceptions about climate variability. When asked about their observation on the behaviour of the weather elements, farmers perceived that the quantum of rainfall decreased over the last few decades, arrival of south-west monsoon progressed during period 1 (1970–1990) and delayed during period 2 (1990–2008). Distribution of rainfall was perceived to be skewed during period 1 and erratic during period 2. Farmers perceived that there was an increase in temperature during period 1 and a major increase in temperature during period 2.

4.11.2 Sri Lanka

Farmers perceived that there was a decrease in annual rainfall, intensity of rainfall, number of rainy days, early arrival of south-west and north-east monsoons and an increase in the duration of dry spells both in Yala and Maha cultivation seasons in all the villages. Farmers perceived that the annual temperature had increased. The perception is the same in all the villages.

4.11.3 Bangladesh

Drought-prone villages

Farmers perceived that in Boikunthapur the onset of the rainy season has gradually been getting delayed, which induced many farmers to try non-traditional crops such as maize in place of wheat. The village has, in some cases, experienced rainfall in the off-seasons too. Farmers perceived that, in Khudiakhali, rainfall quantum and the number of rainy days have declined (by one third on average) in the village. In addition, the farmers observed that incidences of rainfall in the off-season have become less in recent years. Normal onset of the rainy season is delayed by about a month in the village. The village, as a result of its semi-high topography, has faced only a few events of floods and none of them in recent years. The last time that flood submerged the village was in 2004. Farmers in Boikunthapur and its neighbouring villages felt that summer is now becoming hotter and the temperature in the winter is falling, along with very thick fogs and mists. General observations by the farmers in Khudiakhali are that average temperature has been rising during the summer during the last three decades. For the last 5–6 years, the degree of rising temperature has been quite high. During the last decade, drought spells have increased in the area. With such a combination of temperature rise, inadequate rainfall and resulting drought, the water level of the river has decreased in the dry season and people are forced to use diesel-operated water pumps to cultivate betel leaf and other crops, which also increases their production costs. Local people observed that the water depth of the river is at the lowest level in the decade. The groundwater and other surface water sources have also depleted.

Flood-prone villages

In Paschim Bahadurpur, farmers perceive that the intensity and frequency of rainfall has decreased significantly for the last 30–35 years. The villagers said that the extent of rainfall in the dry season has decreased remarkably in the past 10 years. They think that the onset of the rainy season is gradually getting delayed and the duration is also getting shorter. According to the villagers, the number of rainy days is decreasing over the years. Farmers in Nishaiganj felt that average maximum temperature is increasing over the last 10–12 years and the average minimum temperature is increasing, although not very significantly. The villagers from Paschim Bahadurpur observed that temperature is gradually getting warmer every passing year.

4.11.4 Thailand

The actual annual rainfall increased by 3.4% during 1970–1990 and decreased by 3.6% for the lowland villages of Don Plai and Kudsawai. The actual values for both the villages are the same because the data are from a single meteorological station representing both the villages. Farmers perceived that the annual rainfall saw a minor increase in both the periods in Don Plai and farmers in Kudsawai perceived a minor decrease. The actual annual rainfall in the upland villages saw a decrease in the first period (1970–1990) and an increase of 3.5% in the second period (1990–2008). Farmers in both the villages perceived the annual rainfall to witness a minor decrease in both the periods. The actual annual temperature decreased by 0.81°C in the first period and increased by 0.88°C from 1990 to 2008. Farmers perceived it as a minor and major increase in both the periods. It may not have been in great magnitude but the farmers perceived correctly about the latest period. The actual annual temperature in the upland villages of Nong Muang and Tha Taeng decreased by 0.81°C in the first period and increased by 0.91°C in the latest period. Farmers perceived it as a major increase in the first and second periods. If not the magnitude, the trend in the latest period was correctly perceived by the farmers. The actual arrival of the monsoon was earlier by 3.1% in the first period and late by 1.6% in the later period. Farmers perceived that there was no change in the first period and a major delay in the second period. Disregarding the magnitude, the farmers correctly perceived the change in the onset of monsoon in the latest period. In general, farmers' perception about the variability was nearer to the actual observations in the recent period. They were able to recall their latest observations in the recent two decades correctly.

4.11.5 Vietnam

Data are available from only one meteorological station to represent both the villages. Rainfall increased by 14.8% from 1970 to 1990 (period 1) and by 28.3% during 1990–2008 (period 2). Farmers perceived that the annual rainfall saw a major increase during the first and second periods. The actual number of rainy days in the first period decreased by 9.4% and during the second period the number of rainy days increased by 1.7%. Farmers perceived a minor increase in the number of rainy days in the first period and a minor decrease in the second period in Vu Bon village. In Nho Lam village, farmers perceived a minor increase in the first period and a major decrease in the second period. In both cases the farmers were not able to perceive the reality. The reasons need to be clarified through further interpretation. The actual change in annual temperature saw a decrease by 1.5°C. Farmers perceived that there was a minor increase in the temperature during the second period. In general there was a deviation of the farmers' perception and actual observation. The differences between farmers' experiential knowledge and perceptions compared with the inferences drawn from meteorological data need more analysis to identify the reasons for the divergence. The local variability in climate data compared to those collected at a single point needs closer examination. Further, the reliability and validity of information collected must also be closely examined.

4.11.6 China

In Lucheba village the actual annual rainfall increased by 2% during the 1991–2008 period. Farmers perceived it as a 5% increase. In Dajiang village the actual rainfall increased by 0.9% during 1991–2008 and the farmers perceived it as an increase of 5%. The actual annual temperature increased by 1.6% in Lucheba village, whereas the farmers perceived it as an increase of 5%. In Dajiang village the actual annual temperature decreased by 3% in recent times, whereas the farmers perceived it as an increase of 5%. In the majority of study sites, the perceptions of the farmers were in line with the observed trends in climatic changes. Their ability to recall key extreme events also matched the data recorded for the past 40 years in the respective countries.

4.12 Dynamics of Sources and Availability of Water for Irrigation

Water is the most important input in crop production. To insulate crop production from the uncertainties of rainfall, the role of alternate sources of water is critical. Common property sources such as tanks and ponds mostly depend on the rainfall runoff or the catchment area to fill up. Other private sources such as open wells and tube wells tap the groundwater to cater to the needs of irrigation. Sustainable management of groundwater resources is critical to long-term use of these resources.

4.12.1 India

Tank irrigation was common during the 1970s and 1980s. The perception varied from 10% as perceived by large-scale farmers to 18% as perceived by marginal farmers as those dependent on irrigation. Since the 1900s there has not been water in the tanks to irrigate and the tanks dried up. Over time, the catchment area farmers started following water conservation measures such as bunding their fields. The result is that rainfall runoff is considerably reduced and there is almost no water that comes into the tank. In addition, rainfall intensity decreased, which resulted in reduced runoff. Open wells in the village were the major source of irrigation during the 1970s. Perception varied from 82% by marginal farmers to as high as 90% by large-scale farmers for those dependent on irrigation wells. During the 1990s perception about the irrigated area catered for by the wells was more consistent between the groups of farmers. In the recent decade, perception varied from 5 to 6%. Use of wells came down drastically in the recent decade and only about 5% of the irrigated area is catered for by open wells. This is mainly because the groundwater table has receded drastically resulting from over-exploitation and, as a result, most of the wells dried up. During the 1970s groundwater exploitation by deep tube wells was non-existent but in the recent decade there was an enormous increase in the number of tube wells sunk in the village and more than 90% of the irrigated area is irrigated by tube wells. This increased dependence on wells coincided with the decrease in tank irrigation (Fig. 4.4).

Fig. 4.4. Check dam and canals in 1990s opened the way for surface water use to climate-proof agriculture in Shirapur village, Maharashtra, India.

4.12.2 Sri Lanka

Most of the villages in the marginal environments in Sri Lanka are rainfed and quite often there is no other source of irrigation. An irrigation canal is present in Mahagalwewa village and the majority of the farmers felt that there was no change in the quantum of water used for irrigation from the canal in the last four decades. Irrigation from the wells was partially sufficient in Galahitiyagama. Tube wells were not present in Galahitiyagama and very few were present in Mahagalwewa and they were insignificant. In general, irrigation infrastructure, whether collective or private, was very limited in these villages and their potential was limited. Because most of their agriculture is rainfed, farmers are prone to a high risk of uncertainty in rainfall, which has led to increased exposure to spells of water stress and crop loss.

4.12.3 Thailand

There are various sources available for irrigation in the villages in Thailand. The river is one of the major sources across the villages. In lowland villages like Don Plai and Kudsawai the river is close to the fields. In the upland villages like Nong Muang, the river is situated at a distance from the village and the fields. Only very few farms located at the boundary of the village have some access to the river water for irrigation. During recent times farmers using water from rivers varied from 57% in Kudsawai to 24% in Nong Muang. Farmers accessing water from the irrigation canal varied from as high as 87.6% in Don Plai to 6% in Nong Muang. In the upland villages like Nong Muang and Tha Taeng, tube wells, wells and tanks are not important for irrigation. Water sources like these that use either groundwater or runoff have not been explored. Very little area is irrigated in the upland villages and, owing to the topography of most of the land, water does not get accumulated even in the rainy season.

4.12.4 Vietnam

The studied villages represent marginal environments in Vietnam. Both Vu Bon and Nho Lam villages have a canal system for irrigation. It can be seen that in both the villages the percentage of area irrigated increased with time. The main source of irrigation in both the villages was the canal system. In Vu Bon village during the 1990s some wells cropped up and about 10% of the area is irrigated by the wells. It seems that, even though the data show that there was a decrease in rainfed area with time in both the villages, in reality farmers seemed to abandon the rainfed area and stopped cultivating it, and the statistics did not take into consideration the rainfed area to estimate the percentage of area irrigated in recent times.

4.12.5 China

The selected villages represent marginal environments in China. From the 1970s and until recently, most of the croplands were dependent on rainfall in both the villages. In 2009 the government built a large reservoir near Lucheba village and started supplying water directly to the agricultural farms in Lucheba through a pipeline from the reservoir and water tanks near the farms, and then by supplying water from the tanks through pipelines to the fields. Through this system, at present 50% of the area is being irrigated and the remaining 50% of the area is irrigated by tanks. In Dajiang village about 5% of the area is irrigated by tanks and about 32% of the area is irrigated by pumping water from the rivers. This way the lowlands and flat lands are being irrigated. In general, the villages are seeing a development of irrigation infrastructure and this is a good adaptation measure to insulate agriculture from the uncertainties of rainfall and associated dry spells during the crop season. Water is the most important resource that determines production and sustainability of livelihoods. A range of local and external sources of water is seen around the villages. Some do not have access to any form of water other than groundwater that gets depleted during a severe drought. On the other hand, through state intervention many villages are provided with water through tanks, canals and wells. Most villagers perceive the state-sponsored water supply schemes both for home use and irrigation as the most suitable and reliable source.

4.13 Summary and Conclusion

National climate-related policies and programmes are often formulated using the aggregated/macro-level information, projections, modelled scenarios, etc. They seldom consider the micro-level context on response behaviour, existing situation, trends outlook, and coping capacity mainly due to lack of information.

This study demonstrated how observed rainfall data varied at different levels (National→State→District→Mandal/Tehsil→Village) in India and Thailand. A clear divergence of trend was distinctly visible and a huge disconnect between macro- and micro-level information on rainfall pattern was found. In most of the developing countries, the absence of infrastructure for gathering information in a micro-level context often limits the policy machinery to utilize macro-level information for formulating policies for micro-level impacts, thereby missing the targeted need-based approach. This could only be overcome by acquiring micro/village-level information by institutionalizing an efficient mechanism for collecting, collating and channelling micro-level information especially related to weather/climate indicators so as policymakers can use them to formulate effective climate-related measures.

Across South and South-east Asian countries, farmers are trying out new short-duration varieties that are less water demanding. Farmers are also replacing water-intensive crops with drought-tolerant cash crops to optimize their incomes as well as reduce their water needs. They are changing their crop calendar to adjust to the uncertainties of rainfall. These are the important common adaptations of farmers to address the increased variability and uncertainty in rainfall in the marginal rainfed environments across the countries.

Among the farmers in South Asian countries, those in rainfed regions of India have shifted from cereal cultivation to short-duration drought-tolerant or less water demanding crops such as soybean during the last four decades. In places where new irrigation potential has been created, like canals in Shirapur, Maharashtra, sugarcane has replaced many other prevalent crops, which increased incomes. Mixed cropping is being practised in selected villages such as Dokur and Kanzara in Andhra Pradesh as a measure to reduce the risk of income failure. Fodder crops such as maize, grasses and fodder sorghum have gained importance of late as the dairy industry has started to grow in some villages like Aurepalle in Andhra Pradesh and Shirapur in Maharashtra.

In Sri Lanka, cultivation of finger millets, black gram and oilseeds have decreased in recent times, whereas fine cereals and vegetables are increasing. Cotton cultivation is decreasing in most of the villages. Cultivation of annual crops is being reduced in recent decades and farmers are shifting to perennial crops in rainfed villages like Mangalapura in Puttalam district. The shift to perennial crops in Mangalapura is mainly in response to increased uncertainty of rainfall because weatherproofing mechanisms such as the development of irrigation potential did not take place and farmers were unable to cope with crop losses. Hence, farmers perceived that perennial plants like cashew would fare better over time under these harsh rainfed environments.

In South-east Asian countries, rice is the main crop. In addition to rice, cassava is also grown as a main crop in Thailand both in upland and lowland villages. In recent times, however, the cultivated area of cassava is increasing at the expense of rice. Farmers feel that even in the lowland and mid-lowland villages, cassava provides a more stable yield where standing water does not accumulate. Traditional water-intensive crops like kenaf/roselle are slowly disappearing. In Vietnam, hybrid maize is being replaced by inbred maize owing to its low water requirements. In some communes, like Phuoc Nam in Ninh Thuan province, the rice-cultivated area has decreased drastically owing to water unavailability. In coastal villages like in the Phouc Dinh commune, farmers are switching to aquaculture due to saltwater intrusions. In the coastal areas where farmers perceived saltwater intrusions, which altered soil properties, farmers shifted to aquaculture in their traditional rice lands over the last four decades. Boikunthapur district in Bangladesh and Phuoc Dinh commune in Ninh Thuan province in Vietnam are examples of case areas on saltwater intrusion.

The case of China's south-west region, Guizhou province, is different from other countries. The government is focusing on the development of irrigation infrastructure. The idea is to make agriculture climate proof by increasing irrigation potential. Farmers slowly replaced most of traditional crops such as cereals and oilseeds by vegetables and are now cultivating four vegetable crops a year in villages like Lucheba. By increasing crop intensity to 400%, farmers could amply increase profits.

In the study domain, there have been significant changes in cropping pattern, crop and farm management, as well as enterprise diversification which was mostly driven by both price and non-price, including changes in climate and dwindling irrigation potential, saltwater intrusion, and floods, among others. Adoption of improved varieties, short-duration cash crops, drought-tolerant crops, monoculture and a shifting method of rice cultivation are some of the major strategies adopted by the smallholder farmers.

Across the countries, farmers perceived increased mechanization of farm operations with time. This development saw a reduction in the number of bullocks and other farm animals involved in farm operations. One of the downsides is the reduction in the availability of organic manures for soil incorporation. In South Asia, i.e. India, livestock is also an option for income diversification through milk production. The same is true for farmers in selected villages in Sri Lanka, which have diversified income from livestock rearing with a milk production business. These villages have developed milk collection centres and are on the path to commercialize their dairy outputs. Only in one village in Sri Lanka have farmers involved in livestock rearing decreased as early as from the 1970s due to the lack of breeding improvement strategies. The decrease in livestock numbers in villages in recent times is attributed to decreased grazing land and poor maintenance of existing ones.

In South-east Asia, farmers in Thailand raise livestock for personal consumption and as insurance in the event of distress sale. In Vietnam, cows and buffaloes are popular in villages; farmers rear them as an income source. In China's Guizhou province, cows and buffaloes are reared in villages like Lucheba and Dajiang for commercial purposes. Buffaloes are used for farm operations like tillage, etc. Farmers perceived that buffalo numbers decreased in recent times mainly due to increased mechanization and the introduction of mini-tractors and tillers. Farmers perceived that the number of goats increased in the mountainous areas like Dajiang village, thereby increasing the income of the farmers. Livestock rearing and earnings from livestock appeared to be an important cushioning occupation to supplement farmers' income apart from crops. In Sri Lanka, the importance of livestock has decreased, however, possibly owing to the lack of improved breeds and depleted natural resources, viz. grazing lands and water availability.

In South Asia during the 1970s, input markets were still undeveloped at the village levels; farmers had to travel several kilometres to buy seed, fertilizers and pesticides. Input markets and access to input markets in most of the villages in India only developed in recent times and most of the inputs are now available in most villages, except in a few, like Dokur and Kinkheda. In Sri Lanka, most of the input markets are still undeveloped in villages even now. Farmers have to travel a minimum of 10 km to buy inputs. In Thailand, seeds and fertilizers are available in certain villages that experienced some level of development. Output markets to sell agricultural commodities like food grains, oilseeds, pulses, cotton and other crops, dairy and livestock are not well developed in India. Even though there has been some improvement in the last several decades, farmers still have to transport their outputs to nearby markets some 10 to 32 km away, on their own. These markets act as a cushion at times of stress in terms of access and availability. Similar situations were observed in Sri Lanka, Thailand and Vietnam.

Farmers across South and South-east Asian countries and China are diversifying their incomes within the agriculture sector by expanding non-farm enterprise and other income sources. This diversification is mainly dictated by available opportunities, and by infrastructural and governance environments. Among South Asian countries, Indian farmers are keener to diversify their income sources to reduce risk of income loss due to variability and uncertainty in rainfall and associated increased dry spells. The share of agricultural income to total income ranged from 57% to just 13% across the villages. Income from farm work varies between 3% and 16%; businesses from 10% to 19%; and livestock from 4% to 10% of total income. Out-migration and caste occupations are also income sources, albeit insignificant. In Bangladesh, mostly rice and aquaculture predominated in the region but lately with support from government they have started growing high-value crops such as betel leaf, mango, lychee, etc. Sri Lankan farmers too have diversified sources of income but their major source of income is still agriculture, dairy and poultry, and non-farm sources. In Thailand, depending on the water availability, farmers are growing water-intensive crops, e.g. roselle, and comparatively less demanding crops, namely maize, cassava, sugarcane, etc.

Farmers' perception of climate variability echoed many similar observations in all case study countries. Across all selected villages, farmers perceived that there was a decrease in annual rainfall and its distribution was erratic with evidence of a decrease in the number of rainy days. Farmers, except those from Sri Lanka, perceived a delay in the arrival of monsoon and an increase in the annual temperature. Sri Lankan farmers perceived an early arrival of south-west and north-east monsoons and also an increase in dry spells in both Yala and Maha agricultural seasons. In general, farmers' perception about the variability was nearer to actual observations in recent times. They were able to recall their latest observations in the last two decades correctly. Rainfall has been highly variable across the years but district-level rainfall data do not reveal any decreasing trend of annual rainfall. In India, the actual mandal-level data, representing the study villages like Dokur, showed that there was a delay in the arrival of monsoon in the last two decades by about 10 days. Similarly there was a slight decrease in the number of rainy days. The actual temperature increased over time. These findings mostly concur with farmers' perceptions. In Guizhou province of China, the actual annual rainfall increased by 2% in recent times and farmers also perceived an increase in the rainfall but, owing to the erratic nature of the rainfall, the regions remain largely vulnerable. This study throws light on the fact that there is a need for rainfall data collection and its availability at village-level for micro-level planning. Hence, it was evident that there is congruence in the farmers' perception about climatic indicators and professionals' inferences through in depth analysis. Through these 'schools of learning', which are often touted as naïve and traditional, need-based adaptation strategies can be promoted and validated.

Land-management measures using organic matter, such as green manuring and the composting practice of incorporating crop residues into the soil, decreased, whereas field bunding to conserve rainwater and creating drainage channels is followed to varying degrees across villages in India and Sri Lanka. In Thailand, however, mulching (not practised much in India), green manuring, composting and incorporating crop residues are popular in the upland villages, as seen in Tha Taeng and Nong Muang villages, where over 50% of farmers practise them. These practices are not popular with lowland farmers. The reason for the incorporation of organic sources in upland soils in Thailand is due to government interventions in terms of imparting provision of training in organic agriculture to improve soil fertility and water-holding capacity in these villages. Adoption of improved land management is a must for long-term sustainability; concerted efforts through different institutional innovations should be pursued in adopting these locally proven practices.

Water for irrigation is the single most important factor that will neutralize the risk of variability and uncertainty of rainfall. In the 1970s, farmers across the villages in semi-arid regions of India were dependent on tanks and open wells for irrigation. During the 1990s, selected villages (Kanzara, Shirapur and Kinkheda) got infrastructure in terms of canals and surface water for cultivation to insulate crop production from uncertainty of rainfall. Similarly, tube wells were installed in the 1990s, and significantly increased in recent decades, thereby exploiting groundwater. Farmers are aware that in these marginal environments, development of irrigation sources is the key driver of change. One adverse result of this development is that most of the open dug wells started drying up due to lowering of the groundwater table. Many of the tanks also dried up owing to reduced runoff from the catchments. Among the selected Indian villages for the study in the 1970s, water resources development through government interventions in the form of incentives and investments in infrastructure took place. In Sri Lanka, most of the selected villages are rainfed, and much less area is irrigated and a few open wells and tanks are the sources of irrigation. Partial supplementary irrigation is practised during the post-rainy season.

In South-east Asia, irrigation is mainly through surface water from rivers, canals and ponds in lowland villages in Thailand. Besides these, groundwater sources like open wells and tube wells cater to irrigation needs to a limited extent. The condition of lowland villages in Thailand is similar to those in India. By contrast, in the upland villages, very little land is irrigated and the few open wells and ponds are the only sources of irrigation. But unlike Indian villages, the development of groundwater resources in Thailand through investment by farmers is no longer tenable as the groundwater table has gone down significantly. In Vietnam, canal systems, wells and tanks are common in the villages and more than 80% of the irrigation needs are met from the canal system and the rest from open wells and tanks. The dependence on the canal system has increased in recent times. In China, one of the villages in southern Guizhou (Dajiang) has met 50% of its irrigation needs from collected water in about 500 small tanks and the rest of the area is irrigated by a pipeline system and a reservoir built in 2009. By contrast, another village, namely Lucheba in central Guizhou, irrigates only 5% of its cultivated area through tanks and 33% is irrigated by pumping water from a nearby river. Overall, it can be observed that of late, traditional sources of irrigation have weakened not only due to low water tables but also due to the side effects of other factors, namely market, policy, governance structure and demographic changes in China. Hence, there is a need to strengthen indigenous knowledge and traditional mechanisms, especially for conserving the natural resource base.

Notes

1 Decadal analysis was done for 1971, 1981, 1991 and 2001. The data set for the year 2001 was taken as the latest owing to unavailability of data such as population, etc.

2 There is an unavailability of data sets related to coastal districts.

References

Adger, W.N. (2000) Social and ecological resilience: are they related? *Progress in Human Geography* 24(3), 347–364.

Bunce, M., Rosendo, S. and Brown, K. (2010) Perceptions of climate change, multi stressors and livelihoods on marginal African coasts. *Environment, Development and Sustainability* 12, 407–440.

CCAFS (2010) Annual Report. *World's Largest Coalition of Researchers on Climate Change*, Agriculture and Food Security Gears Up! CGIAR Challenge Program on Climate Change, Agriculture and Food Security (CCAFS).

FAO (2004) *Baseline Report on Agro-economic and Social Vulnerability Assessment*. Bangladesh food insecurity and vulnerability information and mapping systems (FIVMS), Food and Agriculture Organization of the United Nations, Rome, p. 66.

IDRC and DFID (2008) *Climate Adaptation in Asia: Knowledge Gaps and Research Issues in China.* The Full Report of the China Team, p. 48.

IPCC (2001) *Climate Change 2001: Impacts, Adaptation and Vulnerability*. IPCC Third Assessment Report, Cambridge University Press, Cambridge, UK.

IPCC (2007) *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability*. Synthesis Report. Summary for Policymakers, Inter-Governmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

MacCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (2001) *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge, UK.

Mertz, O., Mbow, C., Reenberg, A. and Diouf, A. (2009) Farmers' perceptions of climate change and agricultural strategies in rural Sahel. *Environmental Management* 43, 804–816.

Parthasarathy, D. (2009) Social and environmental insecurities in Mumbai: towards a sociological perspective on vulnerability. *South African Review of Sociology* 40, 1.

Sen, A. (1985) *Commodities and Capabilities*. North-Holland, Amsterdam.

Thomas, D.S.G., Twyman, C., Osbahr, H. and Hewitson, B. (2007) Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change* 83, 301–322.

Thornton, P.K., Herrero, M., and Jones, P.G. (2011) Adaptation to climate change in mixed crop-livestock farming systems in developing countries. In: Dinar, A. and Mendelsohn, R. (eds), *Handbook on Climate Change and Agriculture*. Edward Elgar, Cheltenham, UK, p. 402.

5 Climate Change and Food Security in Asia and Africa: Agricultural Futures

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Abstract

This chapter presents the regional level (Asia and Africa) projected impacts of climate change on yield, production, prices, net trade of major crops and food security through to 2050. It also presents the modelling framework that integrates the economic, crop and climate models to assess the impact of climate change scenarios and socio-economic pathways in 2050 at the country level.

5.1 Introduction

Climate change, in terms of both climate means and variability, poses a great threat to the resource-poor farmers the world over, especially in the tropics and semi-arid tropics. The possible impacts include reduced yields, lower farm incomes and reduced welfare. There is increasing awareness of these threats among national and international governments.

Agriculture is vulnerable to climate change in a number of dimensions. Higher temperatures eventually reduce yields and tend to encourage weed and pest proliferation. Greater variations in precipitation patterns increase the likelihood of short-run crop failures and long-term production declines. Although there might be gains in some crops in certain regions of the world, the overall impact of climate change on agriculture is expected to be negative, threatening regional food security in many parts of the developing world that are still predominantly agrarian in nature in particular and world over in general (Appendix 5.1, Table 5.1).

The impact of climate change on agriculture and human welfare include:

- biological effects on crop yields;
- the resulting impact on outcomes including prices, production and consumption;
- the changes in per capita calorie consumption and child malnutrition.

The biological effects of climate change on crop yields induces changes in production and prices, which play out through the economic systems as farmers and other market participants adjust autonomously, altering crop mix, input use, food production, food consumption and trade (Nelson *et al*., 2009).

Climate model simulations for the twenty-first century consistently predict increases in precipitation in the higher latitudes (very likely) and parts of the tropics, and decreases in some subtropical and

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lower and mid-latitude regions. Higher temperatures increase both evaporation and water-holding capacity of the atmosphere, favouring increased climate variability to be exhibited both as more intense precipitation and as more droughts (Bates *et al*., 2008).

As climate change progresses, it is increasingly likely that current cropping systems will no longer be viable in many locations. As mentioned above, a number of processes linked to climate change will impact agricultural productivity. Agricultural productivity is expected to increase slightly in future in mid-to-high latitudes, while decreases are expected in tropical regions. The models have shown positive yield impacts in cooler climates, while decreasing yield levels in lower latitudes where the majority of the developing countries are located (Easterling *et al*., 2007).

Changes in yield of rainfed crops will be driven by changes in both temperature and precipitation, whereas those of irrigated crops will be driven by changes in precipitation alone. Changes in temperature and precipitation regimes are likely to cause the extinction of wild relatives of crops as suitable natural ecosystems would decrease or disappear (Jarvis *et al*., 2008). Owing to global warming, the developing countries face a 9% to 21% decline in overall agricultural productivity, whereas effects on industrialized countries will range from a 6% decline to 8% increase, depending on the offsetting effect the additional atmospheric carbon could have on rates of photosynthesis (Cline, 2007). It is expected that shifts in crop climates to 2050 will result in many countries facing novel climates that are currently not found in their boundaries (Jarvis *et al*., 2011).

The challenges and stresses that face global food production and distribution systems are particularly acute and pressing for sub-Saharan Africa, where persistent levels of food insecurity already exist. About 43% of the population lives below the international poverty line (Dixon *et al*., 2001). Additionally, the area affected by land degradation within the region is expanding, thereby reducing the yield levels further and increasing the difficulties in insufficient food production levels, especially given the lack of technological innovation and low fertilizer use.

According to FAO's recent estimate, the number of people suffering from chronic hunger has increased from under 800 million in 1996 to more than a billion. Most of the world's hungry are in South Asia and sub-Saharan Africa. These regions have large rural populations, widespread poverty and extensive areas of low agricultural productivity owing to steadily degrading resource bases, weak markets and high climate risks. Farmers and landless labourers dependent on rainfed agriculture are particularly vulnerable due to seasonal variability in rainfall and endemic poverty that forces them to avoid risks. Climate change is of particular significance for these countries, which already grapple with global and regional environmental changes and significant inter-annual variability in climate (Vermeulen *et al*., 2012). Climate change will bring further difficulties to millions of people for whom achieving food security is already problematic and is perhaps the most pressing human challenge as we seek to nourish 9 billion people by 2050 (Godfray *et al*., 2010).

5.2 IMPACT Modelling Framework

The International Model for Policy Analysis of Agricultural Commodity and Trade (IMPACT) model combines a partial equilibrium model that has global coverage with hydrology and water supply and demand models and the Decision Support System for Agrotechnology Transfer (DSSAT) crop-modelling suite (Nelson *et al*., 2010). The IMPACT model is a multi-commodity, multi-country partial equilibrium agricultural model for 40 commodities of crop and livestock, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes/meals, sugar/sweeteners, and fruits and vegetables. The IMPACT model includes 281 spatial units, called Food Production Units (FPUs), based on 126 major river basins within 115 regions or country boundaries. The model links the various countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, the rate of productivity growth, investment in irrigation and water availability. Demand is a function of prices, income and population growth. IMPACT contains four categories of commodity demand – food, feed, biofuels feedstock and other uses. The IMPACT model incorporates climate effects from the DSSAT modelling results as a shifter in the supply functions (Robertson *et al*., 2012). The basic IMPACT model is combined with the Water Simulation Model (WSM) in order to estimate the interactions between water supply and demand, and food supply, demand and trade. The scenarios for water are downscaled from and calibrated to Global Circulation Models (GCM) that represent future climates in the different IPCC SRES (Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios) (Nelson *et al*., 2010). In the model, the number of malnourished preschool children in developing countries is a function of per capita calorie availability, the ratio of female to male life expectancy at birth, total female enrolment in secondary education as a percentage of the female age group corresponding to national regulations for secondary education and the percentage of population with access to safe water.

5.2.1 From DSSAT to IMPACT

For input into the IMPACT model, DSSAT is run for five crops – rice, wheat, maize, soybeans and groundnuts – at 30 arc-minute intervals for the locations where the SPAM data set shows where each crop is currently grown. The results from this analysis are then aggregated to the IMPACT FPU level. In extending these results to other crops it is assumed that plants with similar photosynthetic metabolic pathways will react similarly to any climate change effect in a particular geographic region. Millets, sorghum, sugarcane and maize use the C4 pathway. Millets and sugarcane are assumed to have the same productivity effects from climate change as maize in the same geographic regions. Sorghum effects for the Africa region have been modelled explicitly, but for the rest of the world the maize productivity effects were assumed to apply to sorghum as well. The remainder of the crops use the C3 pathway. The climate effects for the C3 crops not directly modelled in DSSAT follow the average for wheat, rice, soy and groundnuts from the same geographic region, with the following exceptions: The IMPACT commodities of 'other grains' and dryland legumes are directly mapped to the DSSAT results for wheat and groundnuts, respectively (Nelson *et al*., 2013).

5.2.2 Modelling climate change in IMPACT

DSSAT has an option to include CO_2 fertilization effects at different levels of CO_2 atmospheric concentration. Climate change effects on crop production enter into the IMPACT model by altering both crop area and yield. Yields are altered through the intrinsic yield growth coefficient and water availability coefficient for irrigated crops. These yield growth rates depend on crop, management system and location. For most crops, the average of this rate is about 1% per year from effects that are not modelled. In some countries, however, the growth in yield is assumed to be negative, whereas in others it is as high as 5% per year for some years.

Climate change productivity effects are produced by calculating location-specific yields for each of the five crops modified with DSSAT for the 2000 and 2050 climate, as described earlier, and are then converted to a growth rate. Rainfed crops react to location-specific changes in precipitation and temperature as modelled in DSSAT. For irrigated crops, temperature effects are modelled in DSSAT with no water stress. Then water stress from climate change is captured as part of a separate hydrology model, a semi-distributed macro-scale hydrology module that covers the global land mass. It stimulates the rainfall-runoff process, portioning incoming precipitation into evapotranspiration and runoff that are modulated by soil moisture content. A temperature reference method is used to judge whether precipitation comes in as rain or snow and determines the accumulation or melting of snow. The model is parameterized to minimize the differences between the simulated and observed runoff. Finally, simulated runoff and evapotranspiration at 30-arc-minute grid cells are aggregated to the FPUs of the IMPACT model (Nelson *et al*., 2010).

5.3 Climate Scenarios

Since the future climate is uncertain, we consider two emission scenarios namely A1B and B1 for the purpose of this study. Each of these two emission scenarios are combined with the two most commonly used general circulation models (GCMs), namely MIROC[1] and CSIRO. On the one hand, the CSIRO model simulates a situation in which there are no increases in precipitation and small increases in temperature. The MIROC model, on the other hand, simulates a future scenario wherein there are the largest increases in rainfall and temperature. The A1B scenario is a greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks mid-century, and the development of new and efficient technologies, along with a balanced use of energy sources. The B1 scenario is a greenhouse gas emission scenario that assumes a convergent world with the same global population, which peaks in the mid-century and declines thereafter, with rapid changes in the structure of the economy towards a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. Thus, we have a total of four climate scenarios. The percentage deviations of the forecast for 2050 from the baseline 2050 values have been reported as they represent the largest of the increases/decreases for the entire time period (2010–2050) for which the IMPACT model makes forecasts. The rationale for reporting the percentage deviations rather than the absolute values is that they are indicative of the direction of change from the baseline values. First, the results for the regions that are the average of all the countries that constitute the region are presented followed by a detailed individual country level discussion because the results at the regional level generally mask the realities at the country level and the inter-country differences within the region.

5.4 Results and Discussion

5.4.1 Baseline

Yield

The yield levels of sorghum, chickpea and pigeonpea are projected to increase in the majority of Asian and African countries. The magnitude of increase, however, differs by both crop and country. Chickpea yields are projected to double in most of the countries. There is a mixed trend as far as sorghum and millets are concerned: a few of the African and Asian countries are to see substantial increments, i.e. above 2 tons/ha, while other countries are to experience marginal increases in their yield levels, i.e. increases of less than 1 ton/ha. Among all the crops considered, pigeonpea is the only crop that has yield levels projected to increase across all countries in Asia and Africa. In contrast to the other dryland crops, the yield levels of groundnut are projected to undergo only marginal changes in most of the Asian and African countries. The increases in the majority of the African countries is less than 1 ton and slightly higher than 1 ton in most Asian countries, with the exception of Indonesia and Iran (Appendix 5.1, Tables 5.2–5.6).

Area

Unlike yields where both Asian and African countries are projected to exhibit somewhat similar trends, the projections for area are quite contrasting. Except for pigeonpea, the area under all crops is projected to change only marginally in Asia, in contrast to Africa where the area under all the 4 crops is projected to increase with a few exceptions. The increases in area are substantial (varies from greater than 50,000 ha to doubling, tripling and quadrupling) for groundnut, sorghum, millets and pigeonpea. These trends are indicative of the fact that most of the yield increases in Africa still continue to come from increases in area under the crops and technological improvements that have still not reached their potential. In sharp contrast to this, the Asian countries are projected to experience only marginal changes (less than 50,000 ha) in area under these crops, with the exception of pigeonpea (Appendix 5.1, Tables 5.2–5.6).

Production

The production of all crops is projected to increase by varying magnitudes in most of the Asian and African countries. The magnitude of increase varies from marginal (less than 50 tons) to increases as high as a five-fold increase. The only exception to this overall positive trend is a few Asian countries where the production of groundnut is projected to decrease and a few Asian and African countries where the production is projected to only marginally decline under the worst of the climate scenarios; the reduction in the Asian countries could be explained as a result of a huge fall in the area under the crop despite having yield improvements (Appendix 5.1, Tables 5.2–5.6).

5.4.2 Scenario results

CSIRO

YIELD. The average per cent yield increases in sorghum in South Asia, South-east Asia and East Asia are 1, 1 and 0.44% relative to the 2050 baseline, respectively. The average per cent yield losses in Northern Africa, Central Africa, Western Africa and Southern Africa are 4, 0.78, 0.22 and 4%, respectively. The average regional millets yields are projected to increase in all Asian countries, whereas in all the African countries it is projected to decline in at least one of the scenarios, with the only exception of Eastern Africa. South-east Asia and Eastern Africa are the only regions that show an increase in average groundnut yields in the B1 scenario. Eastern Africa is the only region that is projected to have increases in its average groundnut yields. In all other Asian and African countries, the average groundnut yields are projected to decline in both scenarios with the magnitude of decline being higher in the A1B scenario. Although the average decline in Asia's chickpea yields is higher in the B1 scenario, in Africa the decreases are higher in the A1B scenario. In Eastern Africa alone, the average chickpea yields are projected to increase by around 9% in both scenarios. The average pigeonpea yields are projected to decline in Asia in both scenarios, with higher declines in the A1B scenario. However, they are projected to increase in the African region in both scenarios with higher increases in the B1 scenario (Appendix 5.1, Tables 5.7–5.11 and Fig. 5.1).

Under the CSIRO scenarios (A1B and B1) India is the only Asian country where the yield level of sorghum and millets are adversely affected. The yield losses are more pronounced for sorghum and millets under the B1 scenario. Besides India, China is the only other Asian country projected to see its millets yield levels decline in the B1 scenario. All other Asian countries are projected to have improvements in their millets and sorghum yield levels. The yield increases in both millets and sorghum are higher in the A1B scenario in all Asian countries except Pakistan and Sri Lanka. Iran is projected to have a 5% increase in its millets yield levels, which is the highest among the Asian countries. Most of the North African countries, except Angola and Sudan, are projected to experience declines in the yield levels of sorghum, groundnut and chickpea. Similarly, most of the Southern African countries are projected to experience declines in the yield levels of sorghum and millets either in both the CSIRO scenarios or at least in one of them. The Central African countries are

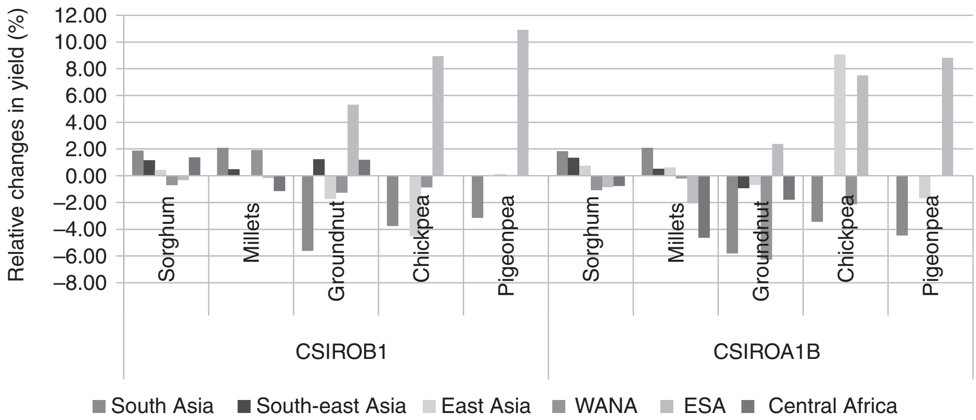

Fig. 5.1. Changes in yield in the CSIRO scenarios.
WANA = West and North Africa; ESA = East and Southern Africa.

projected to experience yield losses in sorghum and millets under the A1B scenario. Among the West African countries, Burkina Faso, Gambia, Mali, Mauritania and Senegal are projected to experience yield losses in sorghum and millets in at least one of the CSIRO scenarios, whereas all other West African countries would actually see their sorghum and millets yield levels improve over the baseline levels. Among the East African countries, Burundi, Kenya, Rwanda and Tanzania are projected to experience yield losses in sorghum and millets under both the CSIRO scenarios. Ethiopia, on the other hand, experiences yield losses in both sorghum and millets only under the B1 emission scenario. In all other East African countries, the yield levels of sorghum and millets are expected to improve over and above their baseline values. The yield levels of groundnut decline in all Asian countries, except India, Indonesia, Vietnam and South Korea in both scenarios and Iran alone in the A1B scenario. Except for the majority of the East African countries, the groundnut yield levels are seen to decline in all other African countries in both scenarios. Namibia sees the highest decline of 22% among the African countries and Burundi sees the highest increase of 35% in the A1B scenario. The yield levels of chickpea are also projected to decline in all Asian countries except Afghanistan and China in both scenarios and Iran in the A1B scenario. Iran sees a 10% increase in its chickpea yield levels in the A1B scenario, which also happens to be the highest increase among all the other Asian countries. Among the African countries, the North African countries of Libya, Morocco and Tunisia see declines in their chickpea yield levels in both scenarios, besides Uganda where yields reduce in the A1B scenario alone. Among the African countries, Morocco is projected to see the highest decline of 4% and Ethiopia is projected to see the highest increase of 22%. Similar to sorghum and millets, the yield declines in groundnut and chickpea are also more pronounced in the A1B scenario in both Asia and Africa. As far as pigeonpea is concerned, their yield levels are projected to increase across all African countries, and in all Asian countries they are projected to decline except in Myanmar. The magnitude of decline is higher in the African countries than the Asian countries in the cases of groundnut, sorghum and millets (Appendix 5.1, Tables 5.7–5.11).

AREA. The average percentage area gains for sorghum in South Asia, South-east Asia, East Asia, Central Africa, Northern Africa, Western, Eastern and Southern Africa are 0.81, 0.81, 0.22, 1.23, 0.75, 1.59, 0.88 and 1.04, respectively. The average percentage area gains for millets are 1.09, 1.67, 0.55,

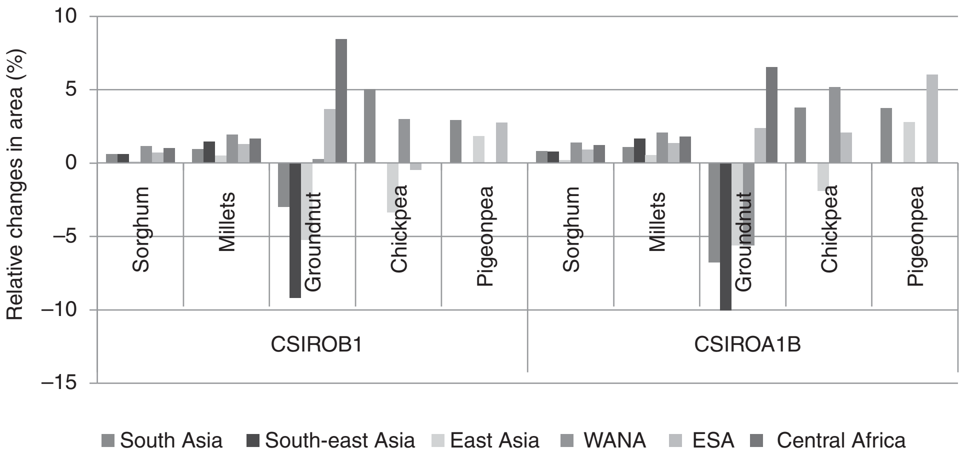

Fig. 5.2. Changes in area in the CSIRO scenarios.
WANA = West and North Africa; ESA = East and Southern Africa.

1.79, 2.10, 1.36, and 1.42% in South Asia, South-east Asia, East Asia, Central Africa, Western Africa, Eastern Africa and Southern Africa, respectively. The average area losses for groundnuts is 7, 10, 6 and 6% in South Asia, South-east Asia, East Asia and West Africa, respectively, and the area gain is 7, 2 and 4% in Central Africa, Eastern Africa and Southern Africa, respectively. The average percentage area gain under pigeonpea is 4% and 6% in Asia and Africa, respectively (Appendix 5.1, Tables 5.7–5.11 and Fig. 5.2).

The area under groundnut is the most adversely affected among the five crops. Among the Asian countries, it reduces in all the countries under both the scenarios except in Myanmar and Pakistan. It is also greatly reduced in most of the West and East African countries under both the scenarios. The area under the chickpea crop is projected to decline under the B1 scenario in India, Bangladesh, Iran and China among the Asian countries and in Uganda among the African countries. Besides these countries, Ethiopia is the only country among all the Asian and African countries that is projected to see a decline in area under chickpea under both the scenarios. South Korea among the Asian countries and Morocco among the African countries are projected to lose area under sorghum under the B1 scenario. Zimbabwe is the only country that is projected to lose area under sorghum in both of the scenarios and with higher area losses in the B1 scenario than in the A1B scenario. Bangladesh, India and Uganda are projected to lose area under pigeonpea. India alone is projected to experience loss in area of pigeonpea under both scenarios, whereas the other two countries would experience area loss only under the B1 emission scenario. The area under the millets crop is projected to increase across all Asian and African countries. Similar to yield declines, the area losses are also more pronounced in the A1B scenario for the four crops than in the B1 scenario. The area losses in the different countries in declining order are groundnut, chickpea, pigeonpea, sorghum and millets (Appendix 5.1, Tables 5.7–5.11).

PRODUCTION. The average percentage increases in sorghum production in South Asia, South-east Asia, East Asia, Central Africa, Western Africa and Eastern Africa are 3, 2, 1, 0.44, 1.37 and 1.39% over and above 2050 baseline levels, respectively, and percentage area losses in Northern and Southern Africa are 3.38 and 3.36% from 2050 baseline levels, respectively. Millets production levels increase in all regions except Central and Southern Africa due to the very high declines in millets production in a few countries in these regions, namely Angola in

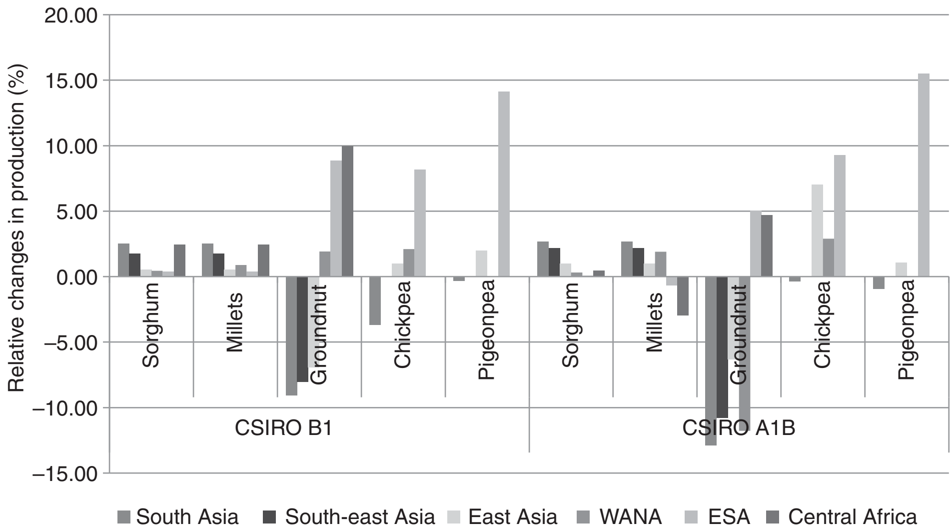

Fig. 5.3. Changes in production in the CSIRO scenarios.
WANA = West and North Africa; ESA = East and Southern Africa.

Central Africa and Namibia and South Africa in Southern Africa. The percentage increases in millets production over and above baseline levels in South Asia, South-east Asia, East Asia, Western Africa and Eastern Africa is 3.2, 2, 1, 2 and 2%, respectively. Except Central Africa and Eastern Africa, all regions are projected to see their groundnut regions decline relative to their 2050 baseline production levels. The chickpea production levels of all the regions are seen to improve, indicating that the reductions in the individual countries are insignificant in affecting the regional trends. The percentage increases in chickpea production relative to the 2050 baseline levels are 6, 3 and 9 in Asia, Northern and Eastern Africa, respectively. Pigeonpea production levels increase relative to the 2050 baseline levels by 14% and 6% in Africa and decrease by 0.25% and increase by 0.47% in Asia in the B1 and A1B scenarios, respectively (Appendix 5.1, Tables 5.7–5.11 and Fig. 5.3).

In line with the reduction in area and yield, the crop whose production is projected to decline in the majority of the Asian and African countries is groundnut. Among the Asian countries, groundnut production is projected to decline in all countries except Indonesia in both scenarios. Malaysia sees a highest decline of 42% among the Asian countries. Among the African countries, groundnut production is projected to decline in Sudan, Ethiopia, Uganda, Zimbabwe, Benin, Burkina Faso, Gambia, Ivory Coast, Mali, Mauritania, Niger, Nigeria, Senegal, Togo, Namibia and South Africa. Except for Thailand, Vietnam, Myanmar and Nigeria, whose yields are adversely impacted only under the A1B scenario, the rest of the above-mentioned countries are projected to experience a reduction in groundnut production levels under both emission scenarios. Among the African countries, Mauritania is projected to experience the highest decline of 48%, while Burundi is projected to see an increase of 35% in groundnut production. The reductions in production are more pronounced in the A1B scenario, as expected. India is the only Asian country to see a decline in sorghum production levels while China and India see their millets production levels decline in the B1 scenario. Among the Asian countries, India, Bangladesh and Iran are projected to see their chickpea production levels decline in both scenarios. Among the African countries Morocco, Tunisia and Uganda see their chickpea production levels fall in one of the scenarios. Among the African countries, the sorghum production of

Egypt, Morocco, Tunisia, Rwanda, Lesotho, Namibia and South Africa is projected to decline under both scenarios, while in Burkina Faso, both sorghum and millets are projected to reduce only under the A1B scenario and in Senegal and Tanzania, the production of both sorghum and millets is projected to increase under the B1 scenario. Similarly, the production of both sorghum and millets is projected to decline in Rwanda, Namibia and South Africa under both scenarios. Besides the above-mentioned countries, the other countries that would experience a reduction in their millets production levels are Angola under both scenarios and Niger under the B1 scenario. The countries that are projected to experience a reduction in chickpea and pigeonpea production are India and Bangladesh under both scenarios and Uganda under the A1B scenario. Besides these countries, Pakistan would be experiencing decline in chickpea production under the A1B scenario and Iran, Morocco and Tunisia under the B1 scenario. The highest decline in chickpea production of 6% is projected to occur in Iran (Appendix 5.1, Tables 5.7–5.11).

MIROC

YIELD. The average percentage losses in sorghum yield levels in South Asia, South-east Asia and Western Africa are 1, 6 and 1%, respectively. The average percentage gains in yields in East Asia, Northern Africa, Central Africa, Eastern Africa and Southern Africa are 20, 4, 11, 13 and 2%, respectively. Unlike the CSIRO scenarios, the MIROC scenario projections on sorghum yields are contrasting for all regions. Except for Western and Southern Africa, all other regions have their average millets yields increase relative to the 2050 baseline. The increases are higher in the A1B scenario for all regions except South Asia. The increases in the average yield levels in South-east Asia, East Asia, Central Africa and Eastern Africa are 5, 23, 6, and 14%, respectively. The increase in South Asia is 3% relative to the baseline 2050. In the case of groundnut, the yield losses are more pronounced in the Asian regions in the A1B scenario, whereas the yield gains are higher in the B1 scenario. In both scenarios, the Asian regions are projected to have yield losses while the averages for all the African regions except Central and Western Africa are positive. The regional averages of chickpea and pigeonpea are positive for both Asia and Africa in the A1B scenario. On the other hand, the Asian region sees its chickpea and pigeonpea yield levels decline in the B1 scenarios (Appendix 5.1, Tables 5.7–5.11 and Fig. 5.4).

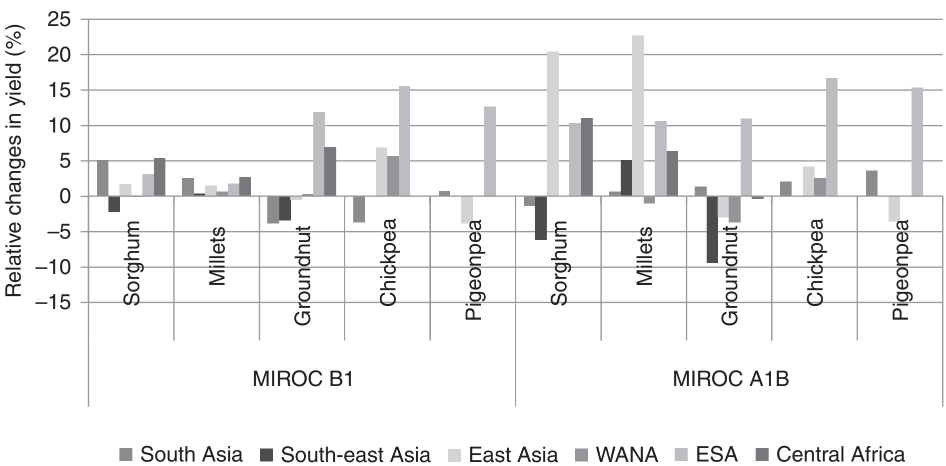

Fig. 5.4. Changes in yield in the MIROC scenarios.
WANA = West and North Africa; ESA = East and Southern Africa.

The projections using the MIROC GCM are not very different from those of the CSIRO model. The MIROC model projections also show that groundnut yield would decline in most of the Asian and African countries under both emission scenarios, with the exception of Sri Lanka, Indonesia, South Korea and Angola, where the groundnut yield levels are projected to marginally improve over the baseline values in the B1 scenario, and Bangladesh, Iran, Senegal and Namibia in the A1B scenario. India is the only Asian country where the groundnut yield levels increase in both scenarios. Burundi, Rwanda, Mali, Sudan and Botswana are projected to see increases in groundnut of more than 20% relative to the 2050 baseline levels in the B1 scenario. Iran, Sudan, Ethiopia, Rwanda, Kenya, Burkina Faso, Niger, Mauritania and Swaziland are projected to see increases of more than 15% in their groundnut yield levels. Kenya is projected to have the highest increase of 24% relative to the 2050 baseline yield levels. The yield levels of sorghum are projected to decline in Pakistan, Thailand and Sri Lanka in the A1B scenario. Thailand is the only Asian country that is projected to have yield losses in the B1 scenario. Among the African countries, Morocco, Tunisia, Mali, Rwanda, Lesotho and South Africa are projected to see yield declines in both scenarios. Unlike the Asian countries where the yield declines are more pronounced in the A1B scenario, African countries suffer from higher yield losses in the B1 scenario. The magnitude of negative impact on millets yields is higher in the A1B scenario, as is the case of most other crops. In addition, the number of countries facing yield losses is also higher in the A1B scenario. Angola, Niger and Iran see their millets yield levels decline under both scenarios. Besides these, Nepal, Pakistan, Benin, Ghana, Ivory Coast, Mali, Sierra Leone, Togo and South Africa are also projected to have millets yield losses in the A1B scenario. Afghanistan, Bangladesh, Nepal, Pakistan, Egypt, Liberia and Tunisia are projected to experience yield losses in chickpea under both scenarios, while Iran would suffer from yield loss only under the B1 scenario. Myanmar, Nepal and Bangladesh are projected to have their pigeonpea yield levels reduced under the climate scenarios (Appendix 5.1, Tables 5.7–5.11).

AREA. In the B1 scenario all regions gain some area under sorghum except East Asia. In the case of millets, South-east Asia and West and Northern Africa also gain some area, whereas all other regions lose some area. All regions except Central Africa lose area under groundnut. In the case of chickpea, West and Northern Africa is the only region that sees area gains. In the case of pigeonpea, South Asia is the only region that gains area among the three growing regions. The trend in the projections for the A1B scenario is quite contrasting to that of the B1 scenario for most of the regions. The area increases under sorghum are more pronounced in the A1B scenario and the difference between these two projections is that East Asia gains some area under sorghum and Central Africa loses area under sorghum, contrary to the B1 projections. In the case of millets, there is trend reversal in East Asia, and West, Northern and Central Africa. The area gains in South Asia, South-east Asia, Eastern and Southern Africa are pronounced in the A1B scenario. East Asia becomes an area gainer in this scenario. In the case of groundnut, West and Northern Africa are the only regions that lose area, while other regions are projected to gain area in varying magnitudes. In the case of chickpea, the trends are similar in both scenarios with the only exception of West and Northern Africa, which loses area. In the case of pigeonpea, South Asia also loses area (Appendix 5.1, Tables 5.7–5.11 and Fig. 5.5).

Unlike the yields the projections for area exhibit a mixed trend and are somewhat positive, in the sense that at least in some countries they are projected to increase in one of the scenarios. There is loss in area under groundnut, sorghum and chickpea in most of the Asian countries and in a few African countries in the B1 scenario. On the positive side, the area under sorghum, millets and groundnut is projected to increase in a few countries in the A1B scenario. The area under sorghum and millets is projected to decline in India, China, South Korea and North Korea among the Asian countries and in Cameroon, Congo, Ghana, Ethiopia,

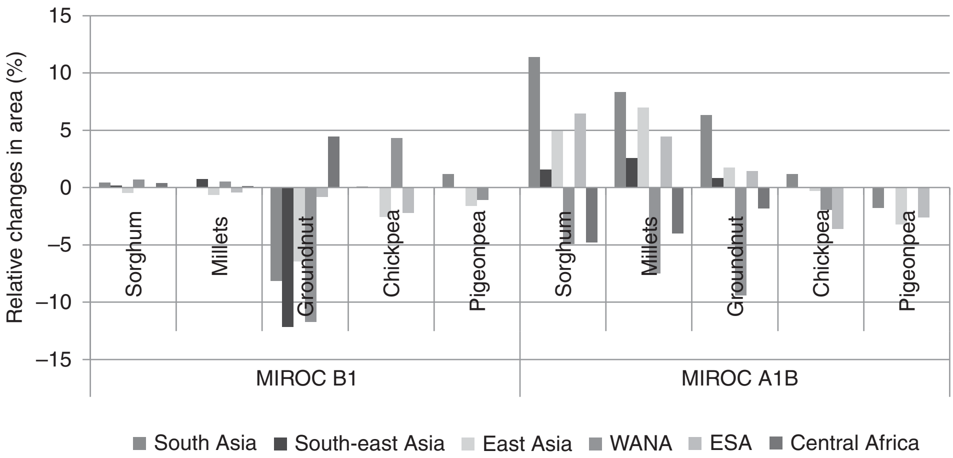

Fig. 5.5. Changes in area in the MIROC scenarios.
WANA = West and North Africa; ESA = East and Southern Africa.

Kenya, Tanzania, Zambia, Zimbabwe, Namibia and South Africa among the African countries. The magnitude of decreases in area under sorghum is higher in Asia, whereas that under millets is higher in Africa. The magnitude of increase differs by country and by crop. In the case of groundnut the area losses are projected to occur in most of the Asian countries only in the B1 scenario, while in the A1B scenario most of the countries are seen to gain area under groundnut. The only Asian countries that would have area gains under groundnut in the B1 scenario are India and Pakistan. Thailand and South Korea alone would lose area under groundnut in the A1B scenario relative to the 2050 baseline levels. All the African countries are to experience groundnut area losses under the B1 scenario, and the Western and Eastern African countries additionally lose area in the A1B scenario. Bangladesh, Iran, Myanmar and China are the Asian countries that see area losses under chickpea in both scenarios, with the effects being more pronounced in the B1 scenario. Among the African countries, Morocco, Tunisia and Kenya are the only countries that see increases in area under chickpea in both scenarios. Morocco gains as much as 28% area relative to the 2050 baseline. Pakistan is the only Asian country that is projected to have area increases under chickpea in the A1B scenario. Among the pigeonpea growing countries, India and Kenya are the only two which are projected to have increased area under pigeonpea, while all other countries are to experience area losses in both the scenarios with the exception of Burundi where there is a very marginal increase in area under pigeonpea (Appendix 5.1, Tables 5.7–5.11).

PRODUCTION. Unlike area, the trends in the case of production are contrasting in both scenarios for all other crops and some regions, except for sorghum and pigeonpea. Except South-east Asia, all regions are projected to have an increased production of sorghum. The increases in production are higher in the A1B scenario than in the B1 scenario, while the declines in production are similar. In the case of pigeonpea, East Asia is the only region that sees a reduction in production in both scenarios. South Asia has similar increases in production in both scenarios, while East and Southern Africa have slightly higher increases in production in the A1B scenario. In the case of millets, the trends are similar in both scenarios except for West and Northern Africa, which are projected to have reductions in production in the A1B scenario. All other regions have increases in production that are pronounced in the A1B scenario. The projections for chickpea for all regions except South Asia, which is projected to have increases in production in the A1B scenario as against the declines in the B1 scenario, are similar. In the case of groundnut, trend reversal is observed in Asia and Central Africa. South Asia and South-east Asia are projected to have increases in production in the A1B scenario contrary to the B1 scenario. Central Africa, on the other hand, is projected to experience declines in production, contrary to the positive picture in the B1 scenario. The reductions in groundnut production are higher in the A1B scenario in two of the African regions.

Similar to area projections, the projections for production also exhibit mixed trends. Thailand and South Korea in Asia and Morocco, Tunisia, Congo, Mali, Rwanda, Zambia, Lesotho and South Africa in Africa are the only countries that are projected to have losses in sorghum production in the B1 scenario. All other countries are to see their sorghum production levels increase relative to the 2050 baseline. The increases are relatively higher in most of the African countries than in Asian countries. In the A1B scenario, Sri Lanka, Papua New Guinea and Thailand among the Asian countries and Morocco, Sudan, Benin, Ghana, Ivory Coast, Mali, Mauritania, Niger, Nigeria, Togo and South Africa are projected to have declines in sorghum production. In all other countries the production levels are projected to increase by more than 10% in most of the Asian and East African countries. Eretria and Somalia see their sorghum productions increase by 45%. Niger sees its production decline by 63% relative to the 2050 baseline levels, which is the highest decrease in Asia and Africa. Iran and South Korea are the only Asian countries that are projected to experience decline in millets production levels in the B1 scenario. Among the African countries, Angola, Mali, Congo, Burundi, Rwanda and South Africa are to see declines in millets production relative to the 2050 baseline. In all other countries it increases. The increases are much higher in the A1B scenario. In the A1B scenario, Iran and Sri Lanka among the Asian countries and Angola, Chad, Benin, Ghana, Mali, Mauritania, Niger, Nigeria, Togo, Botswana and South Africa among the African countries are projected to see declines in millets production. In other Asian and African countries the production levels increase. China is projected to have an increase of 53% and Niger would have a reduction of 63% in millets production, which are the highest increase and decrease levels. All the Asian countries except India are projected to have a decline in groundnut production levels in the B1 scenario. Although all the South-east and East Asian countries are projected to have reductions, the South Asian countries have increases in groundnut production in the A1B scenario. The majority of the West African countries and a few others, namely Ethiopia, Madagascar, Mozambique, Uganda, Zimbabwe, Namibia and South Africa, are projected to see declines in groundnut production levels in both scenarios. In addition to the above-mentioned countries Angola and Sudan are to experience reduction and Uganda, Zimbabwe, and Namibia are to see increases in groundnut production levels in the A1B scenario. Except for the majority of the Eastern African countries, and Morocco and Sudan in Africa, and India and China in Asia, all other chickpea-producing Asian and African countries see their production levels go down either in both or at least in one of the scenarios. Uganda is the only Eastern African country to see declines in chickpea production in both scenarios. Besides Uganda, Malawi is the other Eastern African country which sees decline in chickpea production in the A1B scenario. Pigeonpea production levels are projected to decline in Bangladesh, Myanmar and Uganda in the B1 scenario and in Myanmar, Nepal, Malawi and Uganda in the A1B scenario (Appendix 5.1, Tables 5.7–5.11 and Fig. 5.6).

5.5 Prices

World Prices are a single useful indicator of the effects of climate change on agriculture. Even without climate change, the prices of all five crops increase between 2010 and

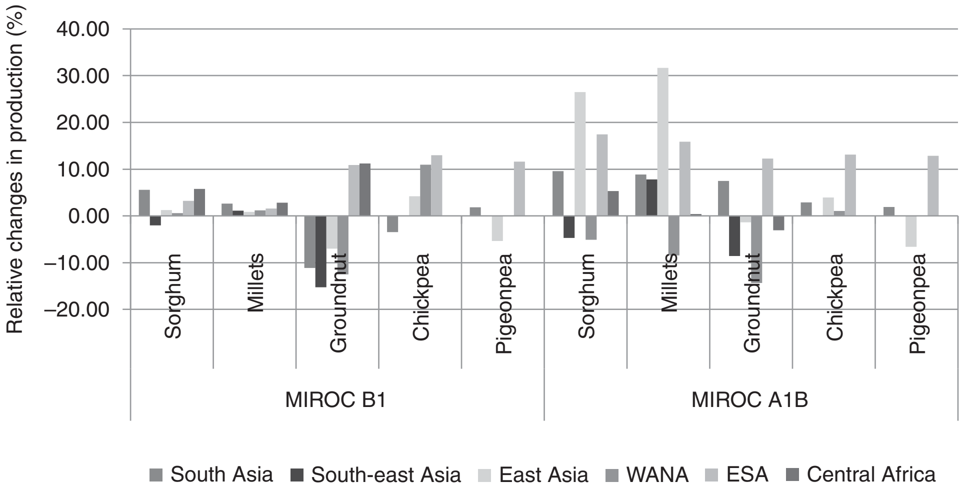

Fig. 5.6. Changes in production in the MIROC scenarios.
WANA = West and North Africa; ESA = East and Southern Africa.

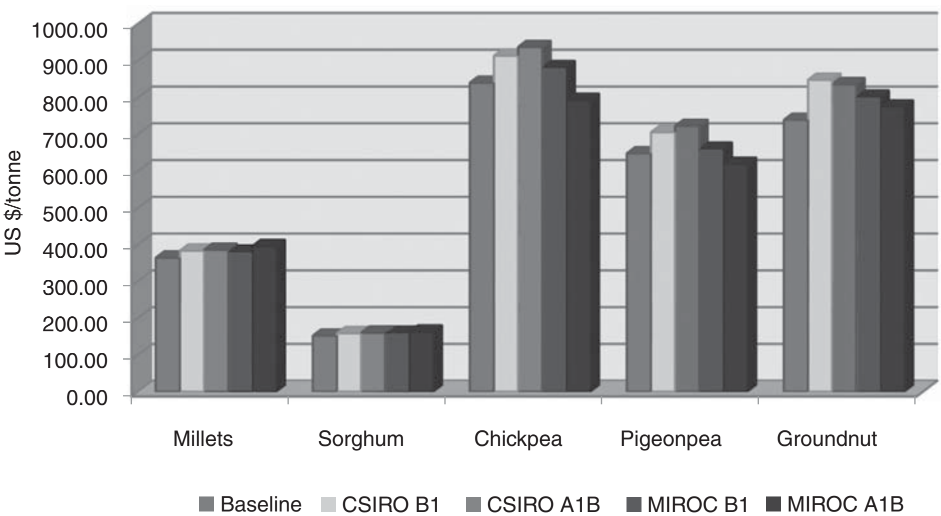

Fig. 5.7. World prices of crops in the different scenarios.

2050. The only crops in which prices decline relative to the baseline scenario are chickpea and pigeonpea in the MIROC A1B scenario. With climate change, the price hikes are accentuated. Table 5.12 (Appendix 5.1) reports the percentage increases in the price levels of the five crops in the alternate climate scenarios, also shown in Fig. 5.7.

The prices of all the crops are projected to increase under all scenarios in varying magnitudes. Among the five crops considered, groundnut prices are projected to increase the most under all scenarios, increasing by almost 15% under the CSIRO B1 scenario (Appendix 5.1, Table 5.12). Sorghum exhibits the least price volatility followed by millets, pigeonpea, chickpea and groundnut. The effects on prices are much higher in the CSIRO than in the MIROC scenario (Fig. 5.7).

5.6 Conclusion and Policy Implication

The results show that yield levels of the crops are likely to decline in most of the Asian and African countries. The area under these crops is also shown to decline in most of the countries. As a result the production levels of these crops get affected adversely, threatening the food security in these regions where these crops hold an important place in their food baskets. Hence, there is an urgent need to undertake more research on these otherwise largely neglected crops to keep pace with climate change and to ensure the food security in these countries where the majority of the world's poor population lives. We need to develop win–win social contracts for sharing technology outcomes with resource-poor countries and encourage more private–public partnerships in the developing world because both are key components of efficient international agricultural research. Looking to 2050 and beyond, the roles of yield growth and productivity improvements remain critical for securing future human well-being. A two-track approach is required in developing countries. It should include global and national food, health and nutrition security initiatives focusing on the vulnerable and an agricultural productivity initiative focusing on small farmers.

Note

1 CSIRO and MIROC are acronyms for general circulation models (GCMs) discussed. CSIRO is a climate model developed at Australia Commonwealth Scientific and Industrial Research Organisation. MIROC is the Model for Interdisciplinary Research on Climate, developed at the University of Tokyo Center for Climate System Research.

References

Bates, B.C., Kundzewicz, Z.M., Wu, S. and Palutikof, J.P. (eds) (2008) *Climate Change and Water.* Technical Paper for the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change, Geneva.

Cline, W.R. (2007). *Global Warming and Agriculture: Impact Estimates by Country*. Center for Global Development and Peterson Institute for International Economics, Washington, DC.

Dixon J.A., Gibbon D.P. and Gulliver, A. (2001). *Farming systems and poverty: improving farmers' livelihoods in a changing world*. Food & Agriculture Organisation and the World Bank, Rome.

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., *et al.* (2007) Food, fibre and forest products. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., Van Der Linden, P.J. and Hanson, C.E. (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK. Available at: http://ccafs.cgiar.org/bigfacts2014/#theme=climate-impacts-production&subtheme=crops (Accessed 6 June 2015).

Godfray, H., Beddington, J., Crute, I., Haddad, L., Lawrence, D., *et al.* (2010) Food Security: The challenge of feeding 9 billion people. *Science* 327(5967), 812–818.

Jarvis, A., Lane, A. and Hijmans, R. (2008) The effect of climate change on crop wild relatives. *Agriculture, Ecosystem & Environment* 126, 13–23.

Jarvis, A., Upadhaya, H., Gowda, C.L.L., Aggarwal, P.K., Fujisaka, S. and Anderson, B. (2011) *Climate Change and Its Effect on Conservation and Use of Plant Genetic Resources for Food and Agriculture and Associated Biodiversity for Food Security.* Thematic Background Study, FAO, Rome.

Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., *et al.* (2009) *Climate Change: Impact on Agriculture and Costs of Adaptation.* International Food Policy Research Institute, Washington, DC.

Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray, I., Ingersoll, C., *et al.* (2010) *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options*. Research Monograph. International Policy Research Institute, Washington, DC.

Nelson, G.C., Plazzo, A., Mason-d'Croz, D., Robertson, R., and Thomas, T.S. (2013) Methodology. In: Jalloh, A., Nelson, G.C., Thomas, T.S., Zougmoré, R. and Roy-Macauley, H. (eds) *West African Agriculture and Climate Change: A Comprehensive Analysis.* Research Monograph. International Food Policy Research Institute, Washington, DC, pp. 37–52.

Robertson, R., Nelson, G., Thomas, T.S. and Rosegrant, M. (2012) Incorporating process-based crop simulation models into global economic Analyses. *American Journal of Agricultural Economics* 95(2), 228–235.

Vermeulen, S.J. Aggarwal, P.K., Ainslie, A., Angelone, C., Campbell, B.M., *et al.* (2012) Options for support to agriculture and food security under climate change. *Environmental Science and Policy* 15, 136–144.

Appendix 5.1

Table 5.1. Changes in the range of yields (tons/ha).

	Baseline		Climate change	
Crop	Africa	Asia	Africa	Asia
Sorghum	5.4	3.84	6.16	17.6
Millets	3.03	1.84	3.02	3.52
Chickpea	3.33	11.3	3.25	12.03
Groundnut	2.2	3.05	2.38	5.4
Pigeonpea	1.21	0.48	1.25	0.52

Table 5.2. Changes in area, production and yield of sorghum in baseline scenario, 2010 and 2050.

	2010			2050					
				Yield		Area		Production	
	Yield	Area	Production	Min	Max	Min	Max	Min	Max
Asia									
Bangladesh	2.24	0.76	1.70	2.94	3.00	0.80	0.82	2.36	2.45
China	3.54	329.77	1,166.13	3.95	4.86	323.53	364.23	1282.82	1,769.76
India	0.84	8,512.45	7,189.46	1.24	1.40	6,833.98	7,429.99	8536.47	10,413.05
Iraq	0.32	3.31	1.07	0.61	0.64	4.14	4.22	2.56	2.68
Kazakhstan	2.52	0.10	0.26	3.31	3.37	0.11	0.11	0.35	0.37
Kyrgyzstan	0.62	0.02	0.01	0.99	1.05	0.02	0.02	0.02	0.02
North Korea	1.84	10.67	19.60	2.05	2.57	11.40	11.57	23.39	29.72
Pakistan	0.30	89.58	26.98	0.37	0.42	89.97	119.08	37.49	43.78
PNG	2.96	1.55	4.59	4.11	4.27	1.46	1.48	6.07	6.25
South Korea	1.35	2.31	3.12	2.01	2.24	2.28	2.33	4.59	5.21
Sri Lanka	0.92	0.27	0.25	1.46	1.76	0.28	0.28	0.41	0.49
Tajikistan	3.53	0.11	0.40	3.74	3.75	0.11	0.12	0.43	0.44
Thailand	2.20	49.46	108.61	3.09	3.48	49.56	50.39	155.79	174.02
Uzbekistan	2.04	3.45	7.03	2.86	2.88	3.49	3.58	10.02	10.33
Africa									
Nigeria	1.20	8,261.62	9,922.53	1.98	2.01	8,450.37	9,113.36	16,744.91	18,123.02
Sudan	0.64	6,204.33	3,966.14	0.68	0.79	7,448.00	8,876.23	5,902.78	6,440.36
Niger	0.38	2,305.24	881.48	0.72	0.76	1,365.24	3,641.70	985.87	2,742.03
Ethiopia	1.57	1,642.04	2,577.03	2.34	2.99	2,488.18	2,680.19	5,870.00	8,014.94
Burkina Faso	1.08	1,627.69	1,755.28	1.69	1.83	2,202.89	2,272.98	3,835.59	4,040.76
Tanzania	1.02	1,067.84	1,088.84	1.98	2.24	1,718.23	1,771.88	3,435.91	3,960.34
Mali	0.84	997.80	842.21	1.65	1.74	1,036.46	1,209.49	1,733.38	2,105.41
Chad	0.72	918.50	657.68	1.03	1.24	1,108.51	1,290.53	1,331.44	1,506.66

continued

Table 5.2. *continued*

	2010			2050					
				Yield		Area		Production	
	Yield	Area	Production	Min	Max	Min	Max	Min	Max
Cameroon	1.20	640.03	765.41	2.17	2.59	1,087.57	1,244.34	2,701.23	2,934.84
Somalia	0.24	636.01	153.48	0.32	0.37	909.14	1,190.59	292.18	420.42
Mozambique	0.49	633.46	307.89	1.00	1.02	1,040.06	1,057.20	1,042.06	1,078.24
Ghana	1.00	372.36	371.53	1.76	1.96	718.29	731.59	1,285.99	1,425.01
Uganda	1.45	370.96	536.86	2.84	3.27	687.67	702.42	1,951.95	2,298.15
Eritrea	0.46	253.41	115.54	0.62	0.76	387.64	449.68	243.03	340.34
Togo	1.24	245.65	305.38	2.10	2.45	483.87	490.33	1,031.61	1,193.22
Rwanda	1.07	229.12	244.69	1.69	2.10	376.97	425.67	637.90	895.59
Benin	0.95	215.59	203.81	1.77	1.88	418.48	425.04	751.90	793.82
Senegal	0.81	184.48	150.14	1.34	1.45	362.37	365.76	487.28	527.06
Mauritania	0.41	183.84	75.63	0.62	0.66	96.73	261.27	63.54	167.12
Kenya	0.83	169.46	140.25	1.42	1.77	310.23	342.74	443.76	607.18
Zimbabwe	0.63	135.67	85.53	1.31	1.40	175.63	180.47	233.59	251.78
Ivory Coast	0.66	120.24	79.53	1.17	1.26	221.82	225.30	262.51	282.61
DRC	0.72	114.74	82.51	1.42	1.48	216.93	225.24	307.35	334.24
South Africa	2.15	82.30	177.19	2.80	3.00	89.72	92.17	254.56	272.64
Malawi	0.66	76.20	50.12	1.35	1.42	125.61	127.70	169.75	181.84
CAR	1.30	63.36	82.23	2.50	2.59	124.80	126.46	313.78	328.05
Botswana	0.28	52.99	14.67	0.57	0.61	70.89	87.99	43.31	50.92

Area in '000 ha; Production in '000 tonnes; Yield in tons/ha.
DRC = Democratic Republic of Congo; CAR = Central African Republic; PNG = Papua New Guinea.

Table 5.3. Changes in area, production and yield of millets in baseline scenario, 2010 and 2050.

	2010			2050					
				Yield		Area		Production	
	Yield	Area	Production	Min	Max	Min	Max	Min	Max
Asia									
Bangladesh	1.17	19.92	29.74	2.11	2.16	20.94	21.44	44.27	46.38
Bhutan	11.06	4.55	6.23	2.03	2.29	4.60	4.70	9.34	10.77
China	182.54	622.94	917.02	1.60	2.10	607.45	715.27	981.33	1503.79
India	34.00	9588.86	8303.80	1.29	1.46	7263.30	8128.16	9465.50	11875.95
Iran	63.96	14.34	11.03	1.03	1.19	17.12	17.76	18.22	20.77
Kazakhstan	481.71	70.30	45.58	0.88	0.90	69.97	72.43	62.22	64.87
Myanmar	0.71	261.47	184.34	1.18	1.23	313.33	319.13	368.63	393.10
Nepal	1.13	276.62	313.95	1.52	1.54	276.99	284.14	421.94	436.90
North Korea	1.37	39.19	53.52	2.13	2.68	41.95	42.89	89.53	114.83
Pakistan	0.22	328.75	72.18	0.26	0.29	329.35	439.21	95.02	113.82
South Korea	0.96	2.34	2.24	1.42	1.59	2.28	2.35	3.25	3.73
Sri Lanka	1.18	6.15	7.27	1.62	1.96	6.29	6.40	10.39	12.29
Uzbekistan	2.10	1.40	2.94	2.71	2.74	1.39	1.44	3.77	3.94
Africa									
Niger	0.45	6224.05	2825.43	0.77	0.79	3293.14	8887.94	2555.87	7054.84
Nigeria	1.28	5680.44	7298.22	1.97	2.00	7959.10	8490.17	15676.36	17001.57
Sudan	0.32	2119.03	680.03	0.48	0.56	2531.46	3053.97	1411.26	1544.45
Mali	214.83	1706.73	1157.19	1.29	1.40	1526.78	1719.17	2033.62	2400.19
Burkina Faso	17.97	1411.17	1165.29	1.43	1.59	1922.09	2003.04	2868.81	3056.65
Chad	151.26	979.97	521.85	1.03	1.38	994.98	1399.40	1368.96	1637.94
Senegal	0.57	839.74	481.71	0.98	1.10	1538.18	1562.29	1526.23	1704.56
Uganda	1.51	503.65	762.09	3.11	3.55	764.23	791.68	2380.16	2809.57
Angola	155.79	422.30	155.79	0.50	0.61	659.09	678.71	333.42	399.84
Ethiopia	55.10	371.09	453.92	2.82	3.49	508.22	546.38	1455.29	1907.20
Namibia	0.23	277.59	63.96	0.46	0.58	430.70	445.30	202.56	255.88
Tanzania	0.78	276.37	214.83	1.35	1.54	410.11	429.04	563.92	661.50
Ghana	7.93	217.56	182.54	1.53	1.71	390.26	402.95	617.65	680.75
Kenya	11.58	132.77	66.46	1.03	1.33	198.96	222.92	208.65	296.39
Zimbabwe	0.34	121.75	41.45	1.19	1.26	174.44	181.55	211.31	228.71
Mozambique	41.45	117.90	34.00	0.48	0.49	183.41	188.83	89.23	92.96
Gambia	66.46	109.17	151.26	2.86	3.06	200.78	206.28	582.43	630.63
Ivory Coast	7298.22	96.92	55.10	1.53	1.66	174.94	180.12	275.83	295.44
Cameroon	49.39	77.63	89.20	2.36	2.66	135.29	141.62	334.37	360.28
DRC	17.48	69.50	49.39	2.12	2.22	122.18	128.02	259.60	284.01
Zambia	0.58	62.92	36.70	1.39	1.43	95.16	98.56	131.86	141.21
Togo	0.90	60.67	54.47	1.77	2.06	111.13	114.16	201.64	231.97
Benin	1165.29	50.39	40.39	2.02	2.15	90.96	93.66	189.48	199.23

Area in ’000 ha; Production in ’000 tonnes; Yield in tons/ha.
DRC = Democratic Republic of Congo.

Table 5.4. Changes in area, production and yield of groundnut in baseline scenario, 2010 and 2050.

	2010			2050					
				Yield		Area		Production	
	Yield	Area	Production	min	max	min	max	min	max
Asia									
Bangladesh	0.84	17.69	14.87	0.73	0.91	15.86	18.47	11.77	16.74
China	1.65	2764.04	4549.21	1.75	1.78	2020.44	2178.79	3554.00	3821.23
India	0.68	5531.31	3772.40	0.64	0.73	4535.99	5023.49	2923.15	3665.66
Indonesia	2.83	776.04	2197.14	2.90	3.23	882.66	937.58	2722.66	2905.52
Iran	1.85	1.14	2.10	1.75	2.49	1.37	1.79	2.40	4.45
Kazakhstan	0.78	0.18	0.14	1.41	1.43	0.17	0.18	0.25	0.26
Kyrkistan	0.02	10.70	0.22	0.04	0.04	9.65	10.25	0.41	0.42
Malaysia	0.78	1.54	1.19	1.17	1.23	0.87	1.54	1.06	1.80
Myanmar	1.08	708.03	767.12	1.09	1.17	714.07	736.28	776.71	862.77
Pakistan	0.53	94.53	50.07	0.50	0.55	89.88	109.29	47.06	58.87
Philippines	0.76	28.48	21.58	0.93	1.00	24.75	30.49	23.74	28.37
South Korea	1.59	2.96	4.71	2.01	2.09	2.47	2.73	5.17	5.50
Sri Lanka	0.64	11.27	7.27	0.54	0.73	9.60	10.94	5.89	6.96
Thailand	1.11	72.41	80.16	1.04	1.30	70.92	73.47	76.33	95.32
Uzbekistan	1.55	4.90	7.57	1.48	1.49	4.69	4.86	6.93	7.26
Vietnam	1.22	150.72	183.97	1.06	1.22	145.14	162.05	166.14	182.62
Africa									
Nigeria	0.76	3262.32	2223.18	0.84	0.97	2845.39	3534.85	2720.40	3202.05
Sudan	0.27	732.75	197.61	0.25	0.30	773.70	1035.10	231.46	269.11
Senegal	0.51	730.63	373.01	0.62	0.69	1262.80	1449.23	841.23	956.48
Chad	0.34	525.04	313.61	0.70	0.89	649.15	966.42	504.86	679.22
DRC	1.04	510.25	276.11	0.63	0.66	998.90	1084.03	634.28	703.22
Ghana	0.88	411.00	254.12	0.72	0.85	398.80	420.53	297.94	355.38
Cameroon	0.41	343.44	140.78	0.63	0.67	354.43	384.36	230.42	250.82
Burkina Faso	0.45	328.01	146.15	0.76	0.97	514.97	535.99	400.69	506.70
Zimbabwe	0.37	289.48	107.79	0.58	0.63	327.99	393.91	200.94	230.34
Nigeria	0.68	282.83	65.52	0.19	0.27	117.35	430.78	29.27	90.19
Mozambique	0.21	271.97	67.30	0.47	0.53	317.25	332.10	152.83	177.14
Uganda	0.51	256.56	129.58	0.43	0.50	363.76	397.10	163.33	199.86
Mali	0.38	249.99	146.36	0.65	0.72	340.40	375.23	232.48	253.44
Guinea	0.89	218.44	192.96	0.89	0.96	318.21	334.32	286.96	320.56
Malawi	0.59	204.17	91.06	0.57	0.60	259.78	274.58	155.85	161.67
Benin	0.64	147.02	94.28	0.59	0.68	218.67	231.52	134.32	157.48
Ivory Coast	0.96	139.71	55.31	0.58	0.73	236.77	250.05	144.41	182.72
CAR	0.78	138.44	108.10	0.88	0.94	177.79	188.33	161.51	176.14
Gambia	0.62	137.61	131.10	0.97	1.05	180.47	195.61	181.51	206.13
Tanzania	0.37	133.28	49.27	0.32	0.34	201.88	213.16	66.81	69.95
Angola	0.22	98.51	21.33	0.23	0.29	97.84	115.81	22.13	33.56
Zambia	0.34	87.86	29.50	0.44	0.47	178.10	187.68	80.97	84.82
Togo	0.50	59.39	29.92	0.42	0.58	93.08	106.61	45.30	57.21
South Africa	1.01	54.92	55.49	1.10	1.20	80.65	84.88	93.05	98.81
Madagascar	0.45	52.99	28.59	0.56	0.62	39.87	41.95	23.29	26.16

Area in '000 ha; Production in '000 tonnes; Yield in tons/ha.
DRC = Democratic Republic of Congo; CAR = Central African Republic.

Table 5.5. Changes in area, production and yield of chickpea in baseline scenario, 2010 and 2050.

	2010			2050					
				Yield		Area		Production	
	Yield	Area	Production	min	max	min	max	min	max
Asia									
Afghanistan	0.64	136.25	86.63	1.39	1.44	135.29	144.77	188.42	208.10
Bangladesh	0.84	15.25	12.79	1.52	1.69	15.95	16.50	25.15	27.02
China	3.89	2.26	8.82	12.54	13.13	2.20	2.27	27.73	29.39
India	0.76	5825.55	4431.60	1.65	1.84	4135.54	4259.95	6883.48	7817.24
Iran	0.38	932.26	351.98	0.65	0.85	904.26	975.29	587.32	828.58
Kazakhstan	0.94	3.77	3.54	2.10	2.16	3.74	4.03	7.84	8.69
Myanmar	1.24	209.36	258.96	1.68	1.74	171.85	183.69	287.87	316.34
Nepal	0.88	10.57	9.35	1.63	1.66	10.49	12.09	17.39	19.90
Pakistan	0.62	1143.06	706.87	0.94	1.11	1273.65	1643.00	1292.03	1715.92
Uzbekistan	0.36	0.23	0.08	1.00	1.03	0.23	0.25	0.23	0.25
Africa									
Algeria	0.76	12.94	9.89	1.27	2.60	13.40	16.71	17.48	43.49
Egypt	1.90	6.17	11.71	3.53	3.82	6.00	6.68	21.21	25.29
Eritrea	0.24	20.87	5.06	0.40	0.46	21.87	23.97	9.59	10.71
Ethiopia	1.08	180.19	195.21	2.33	2.42	210.59	238.18	510.31	559.20
Kenya	0.25	37.60	9.26	0.52	0.70	74.09	81.68	40.48	54.16
Libya	0.88	0.40	0.35	1.41	1.53	0.48	0.52	0.67	0.80
Malawi	0.42	93.68	39.22	1.22	1.30	126.29	137.04	153.51	176.02
Morocco	0.70	86.75	60.84	1.40	1.79	101.04	127.77	147.22	229.09
Sudan	1.43	2.65	3.80	2.54	3.15	3.28	4.10	9.97	11.62
Tanzania	0.42	82.01	34.48	0.65	0.70	135.49	151.12	94.51	99.05
Tunisia	1.04	11.98	12.48	2.15	2.31	14.66	16.05	31.46	36.99
Uganda	0.53	7.23	3.87	1.00	1.07	9.72	10.51	10.34	11.10

Area in ’000 ha; Production in ’000 tonnes; Yield in tons/ha.

Table 5.6. Changes in area, production and yield of pigeonpea in baseline scenario, 2010 and 2050.

	2010			2050					
				Yield		Area		Production	
	Yield	Area	Production	Min	Max	Min	Max	Min	Max
Asia									
Bangladesh	0.46	3.40	1.58	0.75	0.84	2.60	2.82	2.60	2.82
India	0.65	3048.06	1983.98	1.25	1.40	3904.11	4371.18	3904.11	4371.18
Myanmar	0.91	665.82	605.60	1.24	1.29	877.23	957.89	877.23	957.89
Nepal	0.91	21.72	19.79	1.13	1.15	25.82	29.35	25.82	29.35
Africa									
Burundi	0.91	2.17	1.98	1.43	1.46	1.53	1.77	2.19	2.58
Kenya	0.51	203.59	103.66	0.79	0.98	228.06	250.96	186.72	234.79
Malawi	0.68	135.45	91.82	2.04	2.16	187.94	202.00	382.56	433.51
Tanzania	0.75	77.90	58.03	1.18	1.27	106.73	117.79	135.66	139.44
Uganda	1.07	98.14	104.60	1.89	2.03	134.90	145.57	268.53	291.42

Area in ’000 ha; Production in ’000 tonnes; Yield in tons/ha.

Table 5.7. Impact of alternative climate scenarios on sorghum (percentage deviations from baseline, 2050).

	CSIRO B1			CSIRO A1B			MIROC B1			MIROC A1B		
	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production
Asia												
South Asia	1.88	0.63	2.52	1.85	0.81	2.68	5.13	0.45	5.60	–1.36	11.40	9.56
Bangladesh	0.59	0.55	1.14	0.69	0.76	1.46	0.68	0.50	1.18	2.57	2.13	4.75
India	–1.63	0.19	–1.45	–0.08	0.30	0.22	6.59	–0.44	6.12	11.06	8.24	20.22
Pakistan	4.24	0.54	4.80	4.04	0.75	4.82	5.77	0.59	6.40	–8.05	33.08	22.37
Sri Lanka	4.32	1.23	5.59	2.74	1.44	4.23	7.49	1.13	8.71	–11.03	2.16	–9.10
South-east Asia	1.13	0.62	1.76	1.34	0.81	2.15	–2.24	0.17	–2.05	6.16	1.53	4.71
PNG	0.49	1.09	1.58	0.57	1.32	1.90	0.56	0.96	1.52	–3.03	2.00	–1.09
Thailand	1.78	0.16	1.95	2.11	0.29	2.41	–5.03	–0.62	–5.62	–9.29	1.06	–8.32
East Asia	0.44	0.11	0.55	0.75	0.22	0.97	1.69	–0.43	1.26	20.42	4.93	26.47
China	0.39	0.25	0.64	1.17	0.38	1.56	4.02	–0.13	3.89	23.49	12.43	38.84
North Korea	0.51	0.22	0.73	0.60	0.32	0.93	0.59	–0.21	0.37	25.90	1.29	27.53
South Korea	0.41	–0.15	0.26	0.48	–0.04	0.44	0.47	–0.94	–0.47	11.86	1.05	13.04
Africa												
Northern Africa	–3.39	0.53	–2.87	–4.10	0.75	–3.38	–4.03	0.08	–3.94	4.35	9.23	12.89
Algeria	2.49	0.33	2.83	0.51	0.57	1.08	3.59	–0.20	3.38	3.38	2.22	5.67
Egypt	–2.01	–0.05	–2.06	–2.43	0.07	–2.37	–6.14	–0.98	–7.06	–6.08	1.45	–4.71
Morocco	–6.82	–0.02	–6.83	–8.44	0.09	–8.36	–10.44	–0.91	–11.25	–3.71	15.05	10.78
Sudan	1.47	1.10	2.58	0.83	1.32	2.16	7.54	0.88	8.49	16.96	–14.99	–0.57
Tunisia	–10.71	0.72	–10.07	–9.29	1.02	–8.37	–16.82	0.55	–16.36	0.76	34.63	35.66
Central Africa	–10.71	0.72	–10.07	–9.29	1.02	–8.37	5.41	0.36	5.80	11.06	–4.74	5.28
Cameroon	1.69	0.94	2.64	–2.99	1.08	–1.94	6.50	0.03	6.54	15.61	–11.66	2.13
CAR	0.14	1.64	1.78	–0.48	1.98	1.49	1.19	1.32	2.52	3.35	2.67	6.11
Chad	3.17	1.10	4.30	–0.29	1.32	1.03	13.32	0.88	14.32	19.89	–12.97	4.34
DRC	0.54	0.46	1.00	0.63	0.56	1.19	0.62	–0.80	–0.19	5.38	3.00	8.55
Western Africa	0.07	1.33	1.40	–0.22	1.59	1.37	1.00	0.85	1.85	–1.21	–8.94	–10.24
Benin	0.54	1.33	1.88	0.63	1.50	2.14	0.62	0.48	1.10	–5.21	2.06	–3.26
Burkina Faso	1.05	0.95	2.01	–2.17	1.01	–1.18	3.83	0.26	4.10	6.01	–2.11	3.78
Gambia	–1.29	1.76	0.45	–1.11	2.15	1.01	2.10	1.44	3.57	4.45	2.81	7.38

Ghana	0.54	0.93	1.47	0.63	1.20	1.85	0.62	0.23	0.85	–9.97	2.09	–8.09
Guinea	0.54	1.64	2.19	0.63	1.98	2.62	0.62	1.32	1.94	2.55	2.67	5.29
Guinea Bissau	0.54	1.76	2.31	0.63	2.15	2.79	0.62	1.44	2.06	3.27	2.81	6.17
Ivory Coast	0.54	1.33	1.88	0.63	1.50	2.14	0.62	0.48	1.10	–7.04	2.06	–5.12
Mali	–0.75	1.10	0.34	–2.17	1.32	–0.89	–5.89	0.88	–5.06	–4.86	–13.18	–17.39
Mauritania	–0.22	0.70	0.49	–1.70	0.90	–0.81	1.53	0.26	1.80	3.61	–62.64	–61.29
Niger	–0.05	1.10	1.04	0.95	1.32	2.28	3.08	0.88	3.98	–1.57	–62.02	–62.61
Nigeria	0.59	1.03	1.63	0.44	1.25	1.69	1.52	0.23	1.75	0.14	–6.12	–5.98
Senegal	–2.06	1.64	–0.45	–1.71	1.98	0.24	3.51	1.32	4.87	6.57	1.03	7.67
Sierra Leone	0.54	1.64	2.19	0.63	1.98	2.62	0.62	1.32	1.94	–1.28	2.67	1.36
Togo	0.54	1.64	2.19	0.63	1.98	2.62	0.62	1.32	1.94	–13.58	2.67	–11.28
Eastern Africa	0.90	0.69	1.60	0.51	0.88	1.39	4.66	–0.00	4.66	13.29	7.42	21.92
Burundi	–0.88	1.15	0.26	–0.99	1.37	0.37	–0.10	0.47	0.37	15.08	2.63	18.11
Eritrea	3.04	0.77	3.83	2.50	1.00	3.53	18.95	0.33	19.34	24.57	16.39	44.98
Ethiopia	–0.48	0.11	–0.37	0.49	0.11	0.61	8.79	–0.85	7.86	27.38	6.80	36.04
Kenya	–0.01	0.35	0.34	–0.15	0.61	0.46	8.03	–0.26	7.75	24.59	10.19	37.29
Madagascar	0.69	0.46	1.16	0.81	0.60	1.42	0.79	–0.32	0.47	1.65	2.01	3.69
Malawi	0.69	1.21	1.91	0.81	1.52	2.35	0.79	0.79	1.59	6.20	2.47	8.82
Mozambique	1.25	1.09	2.35	0.83	1.35	2.19	1.15	0.66	1.82	2.96	2.32	5.35
Rwanda	–1.36	1.15	–0.22	–2.22	1.37	–0.88	–4.00	0.47	–3.54	19.36	13.45	35.42
Somalia	1.67	1.33	3.02	–0.58	1.57	0.97	14.02	1.11	15.28	9.73	32.41	45.29
Tanzania	–0.50	0.15	–0.35	0.91	0.30	1.21	3.91	–0.81	3.07	12.29	2.29	14.86
Uganda	0.69	1.15	1.85	0.81	1.37	2.19	0.79	0.47	1.27	16.18	2.63	19.23
Zambia	0.69	0.26	0.95	0.81	0.36	1.18	0.79	–0.82	–0.04	3.91	1.42	5.38
Zimbabwe	6.24	–0.21	6.02	2.62	–0.13	2.48	6.65	–1.29	5.27	8.91	1.43	10.47
Southern Africa	–3.55	0.79	–2.78	–4.38	1.04	–3.36	–0.82	0.13	–0.63	2.68	3.94	5.78
Botswana	0.19	1.21	1.40	–0.40	1.52	1.12	1.98	0.79	2.78	6.86	–18.21	–12.59
Lesotho	–13.60	0.69	–13.01	–8.06	0.97	–7.16	–11.88	–0.06	–11.93	–10.87	31.74	17.42
Namibia	–3.55	0.73	–2.84	–10.20	1.02	–9.28	4.82	0.31	5.14	4.68	2.08	6.86
South Africa	–4.73	0.13	–4.61	–11.07	0.17	–10.91	–9.92	–1.13	–10.93	–8.90	1.57	–7.46
Swaziland	3.94	1.19	5.18	7.82	1.48	9.42	10.93	0.76	11.78	21.62	2.49	24.66

Area in ’000 ha; Production in ’000 tonnes; Yield in tons/ha.
DRC = Democratic Republic of Congo; CAR = Central African Republic; PNG = Papua New Guinea.

Table 5.8. Impact of alternative climate scenarios on millet (percentage deviations from baseline, 2050).

	CSIRO B1			CSIRO A1B			MIROC B1			MIROC A1B		
	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production
Asia												
South Asia	2.10	0.98	3.10	2.08	1.09	3.20	2.54	0.03	2.59	0.62	8.31	8.86
Bangladesh	0.71	0.92	1.63	0.80	1.07	1.87	0.61	0.31	0.92	2.95	2.70	5.73
Bhutan	0.62	1.29	1.92	0.69	1.46	2.16	0.53	0.53	1.06	13.51	2.62	16.48
Iran	4.69	0.55	5.27	5.12	0.59	5.74	–3.76	–1.15	–4.86	–9.52	2.54	–7.22
Nepal	0.62	0.77	1.39	0.69	0.86	1.56	0.53	–0.16	0.37	1.48	2.41	3.93
Pakistan	5.09	1.03	6.18	4.87	1.19	6.12	6.80	0.47	7.31	–5.13	33.99	27.11
Sri Lanka	4.05	1.61	5.73	2.63	1.77	4.44	6.82	0.93	7.81	–11.33	2.77	–8.88
India	–1.11	0.65	–0.46	–0.21	0.69	0.48	6.27	–0.69	5.54	12.38	11.13	24.89
South-east Asia	0.46	1.49	1.95	0.52	1.67	2.20	0.40	0.71	1.11	5.11	2.57	7.82
Myanmar	0.46	1.49	1.95	0.52	1.67	2.20	0.40	0.71	1.11	5.11	2.57	7.82
East Asia	0.02	0.50	0.52	0.64	0.55	1.19	1.51	–0.63	0.87	22.72	6.98	31.66
China	–1.05	0.63	–0.42	0.66	0.71	1.37	3.58	–0.34	3.23	30.03	17.36	52.59
North Korea	0.62	0.56	1.18	0.69	0.61	1.31	0.53	–0.40	0.13	26.12	1.83	28.43
South Korea	0.49	0.30	0.79	0.55	0.33	0.89	0.42	–1.17	–0.75	12.01	1.75	13.97
Africa												
Central Africa	–1.14	1.67	0.50	–4.65	1.79	–2.95	2.70	0.10	2.82	6.34	–3.98	0.39
Angola	–11.88	1.75	–10.34	–22.36	1.93	–20.86	–5.45	0.38	–5.09	–21.65	3.37	–19.01
Cameroon	1.14	1.60	2.76	–0.78	1.64	0.84	3.02	–0.32	2.70	11.91	–2.91	8.65
CAR	0.16	2.31	2.47	–0.64	2.54	1.89	1.27	0.96	2.24	3.70	3.71	7.55
Chad	4.21	1.57	5.85	–0.17	1.72	1.54	14.13	0.63	14.85	32.73	–27.68	–4.01
DRC	0.65	1.12	1.78	0.73	1.11	1.85	0.56	–1.14	–0.59	5.00	3.58	8.75
Western Africa	1.93	1.93	1.91	–0.19	2.10	1.90	0.68	0.53	1.21	–1.00	–7.45	–8.45
Benin	2.00	2.00	2.66	0.73	2.06	2.80	0.56	0.13	0.69	–5.17	3.10	–2.23
Burkina Faso	1.42	1.42	3.14	–2.26	1.41	–0.88	5.59	0.01	5.60	8.51	–2.68	5.61

Gambia	2.43	2.43	0.95	–1.27	2.71	1.41	2.26	1.08	3.36	5.24	3.86	9.30
Ghana	1.59	1.59	2.25	0.73	1.77	2.50	0.56	–0.12	0.44	–9.82	3.13	–7.00
Guinea	2.31	2.31	2.97	0.73	2.54	3.29	0.56	0.96	1.52	2.43	3.71	6.23
Guinea Bissau	2.43	2.43	3.09	0.73	2.71	3.46	0.56	1.08	1.65	3.44	3.86	7.43
Ivory Coast	2.00	2.00	2.66	0.73	2.06	2.80	0.56	0.13	0.69	–6.91	3.10	–4.02
Mali	1.57	1.57	1.17	–2.32	1.72	–0.64	–8.23	0.63	–7.65	–5.11	–9.67	–14.28
Mauritania	1.18	1.18	1.22	–1.36	1.30	–0.08	1.38	0.01	1.39	0.50	–54.60	–54.38
Niger	1.57	1.57	–0.79	1.26	1.72	3.00	–0.56	0.63	0.06	–0.99	–62.31	–62.69
Nigeria	1.61	1.61	2.18	0.62	1.74	2.37	0.51	–0.07	0.43	–1.03	–4.63	–5.61
Senegal	2.31	2.31	–0.68	–2.47	2.54	0.01	4.63	0.96	5.64	9.40	1.40	10.93
Sierra Leone	2.31	2.31	2.97	0.73	2.54	3.29	0.56	0.96	1.52	–1.11	3.71	2.56
Togo	2.31	2.31	2.97	0.73	2.54	3.29	0.56	0.96	1.52	–13.43	3.71	–10.22
Eastern Africa	0.88	1.27	2.10	0.45	1.36	1.82	3.36	–0.40	2.93	14.05	6.54	21.73
Burundi	–1.29	1.84	0.52	–1.48	1.95	0.44	–0.80	0.11	–0.69	15.44	3.71	19.72
Eritrea	2.08	1.24	3.35	1.83	1.40	3.25	10.99	0.08	11.08	18.02	17.25	38.37
Ethiopia	–0.10	0.58	0.48	0.66	0.51	1.18	6.93	–1.10	5.75	23.85	6.33	31.68
Kenya	–0.09	1.03	0.95	–0.34	1.19	0.85	10.73	–0.62	10.05	28.65	11.35	43.25
Malawi	0.83	1.83	2.68	0.93	2.05	3.00	0.72	0.46	1.18	6.44	3.44	10.10
Mozambique	2.62	1.71	4.37	0.97	1.88	2.87	1.85	0.33	2.19	3.06	3.30	6.46
Rwanda	–2.34	1.84	–0.54	–3.76	1.95	–1.89	–6.72	0.11	–6.62	17.48	14.65	34.69
Tanzania	–0.97	0.83	–0.15	1.21	0.87	2.09	5.32	–1.16	4.10	13.28	3.40	17.13
Uganda	0.83	1.84	2.69	0.93	1.95	2.90	0.72	0.11	0.83	14.77	3.71	19.02
Zambia	0.83	0.87	1.71	0.93	0.88	1.83	0.72	–1.15	–0.44	4.14	2.38	6.62
Zimbabwe	7.22	0.40	7.66	3.08	0.39	3.48	6.52	–1.62	4.80	9.38	2.39	12.00
Southern Africa	–3.96	1.30	–2.70	–11.08	1.42	–9.78	–4.0	–0.034	–4.23	–1.83	–3.23	–5.57
Botswana	0.49	1.83	2.33	–0.43	2.05	1.61	3.41	0.46	3.88	8.04	–15.56	–8.77
Namibia	–4.81	1.35	–3.52	–15.14	1.55	–13.83	5.61	–0.02	5.59	5.31	3.37	8.85
South Africa	–7.56	0.72	–6.89	–17.67	0.68	–17.11	–21.02	–1.44	–22.16	–18.83	2.51	–16.79

Table 5.9. Impact of alternative climate scenarios on groundnut (percentage deviations from baseline, 2050).

	CSIRO B1			CSIRO A1B			MIROC B1			MIROC A1B		
	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production
Asia												
South Asia	–5.62	–2.99	–9.05	–5.81	–6.77	–12.90	–3.81	–8.10	–11.14	1.32	6.30	7.50
Bangladesh	–13.96	–10.86	–23.30	–16.82	–11.48	–26.37	–9.33	–13.10	–21.21	3.45	1.20	4.70
India	1.10	–1.98	–0.90	0.70	–6.13	–5.47	12.88	1.38	14.44	14.03	3.96	18.54
Iran	–2.88	–18.04	–20.40	9.35	–19.20	–11.64	–18.94	–20.07	–35.21	15.71	4.08	20.44
Pakistan	–15.78	24.70	5.02	–17.41	12.41	–7.16	–12.75	2.55	–10.52	–7.53	21.06	11.94
Sri Lanka	3.42	–8.78	–5.66	–4.87	–9.46	–13.87	9.09	–11.25	–3.18	–19.05	1.18	–18.09
South-east Asia	1.24	–9.21	–8.02	–0.89	–10.02	–10.79	–3.37	–12.13	–15.26	–9.41	0.83	–8.62
Indonesia	2.51	–0.87	1.61	2.85	–1.86	0.93	3.99	–4.26	–0.44	–6.37	1.69	–4.78
Malaysia	0.34	–40.44	–40.24	–1.89	–40.97	–42.08	–1.43	–42.28	–43.11	–4.80	1.64	–3.24
Myanmar	–0.04	2.57	2.53	–4.18	1.68	–2.58	–7.21	–0.52	–7.69	–5.84	0.59	–5.28
Thailand	2.03	–0.36	1.66	–1.78	–1.28	–3.03	–7.28	–3.83	–10.83	–18.19	–0.50	–18.60
Vietnam	1.35	–6.95	–5.69	0.53	–7.70	–7.21	–4.91	–9.77	–14.20	–11.84	0.74	–11.19
East Asia	–1.73	–5.22	–6.92	–0.68	–5.62	–6.32	–0.51	–6.43	–7.05	–3.02	1.72	–1.40
China	–5.28	–3.82	–8.90	–4.13	–3.74	–7.71	–4.60	–2.91	–7.37	–5.56	3.72	–2.05
South Korea	1.81	–6.62	–4.93	2.78	–7.50	–4.94	3.58	–9.94	–6.72	–0.47	–0.28	–0.75
Africa												
Central Africa	1.19	8.46	9.95	–1.79	6.55	4.68	6.92	4.44	11.19	–0.41	–1.79	–3.11
Angola	6.29	18.87	26.35	0.92	17.20	18.27	6.38	13.51	20.75	–17.04	0.43	–16.69
Libya	–1.07	5.89	4.76	–1.59	4.72	3.06	–3.80	1.52	–2.34	–5.27	0.71	–4.60
Morocco	–3.14	3.50	0.25	–6.05	7.14	0.66	4.58	12.62	17.79	2.35	12.80	15.46
Sudan	2.70	5.58	8.43	–0.42	–2.86	–3.27	20.51	–9.91	8.58	18.33	–21.08	–6.61
Eastern Africa	–3.72	5.23	1.59	–7.50	3.78	–4.05	12.36	–1.21	11.12	1.74	1.71	13.96
Burundi	24.79	10.51	37.90	24.24	8.81	35.18	24.20	4.66	29.99	23.59	0.64	24.38
Eritrea	2.98	5.52	8.66	2.48	4.50	7.09	8.80	1.72	10.66	8.05	0.36	8.43
Ethiopia	19.84	–18.30	–2.08	22.28	–25.03	–8.32	25.58	–25.84	–6.87	23.56	–1.45	21.76

Kenya	9.64	8.79	19.27	4.89	16.17	21.85	14.95	14.87	32.05	33.30	18.01	57.32
Madagascar	0.34	0.32	0.66	–1.26	–1.15	–2.39	–2.78	–4.66	–7.31	–10.50	0.12	–10.40
Malawi	10.28	–0.23	10.03	9.90	–1.53	8.22	11.28	–4.68	6.07	5.56	0.75	6.35
Mozambique	6.73	3.37	10.32	–0.89	1.97	1.06	–3.61	–1.25	–4.81	–4.98	0.61	–4.41
Rwanda	–3.73	38.00	32.86	–6.28	36.01	27.48	23.14	30.70	60.95	24.73	0.97	25.94
Tanzania	6.39	4.12	10.77	6.13	2.37	8.65	11.53	–1.39	9.98	13.33	0.37	13.75
Uganda	2.13	–2.70	–0.63	–5.90	–4.22	–9.87	3.93	–7.71	–4.09	9.47	0.74	10.29
Zambia	8.70	1.20	10.01	10.97	–0.33	10.60	13.48	–3.96	8.98	5.88	–0.28	5.58
Zimbabwe	11.78	–12.49	–2.18	9.91	–13.83	–5.29	17.78	–16.96	–2.20	8.86	–0.27	8.56
Western Africa	–1.27	0.28	–0.99	–6.27	–5.61	–11.77	0.32	–11.71	–12.53	–3.70	–9.38	–14.33
Benin	–9.02	–0.28	–9.28	–21.16	–1.85	–22.62	–15.55	–5.58	–20.26	–17.63	–0.02	–17.65
Burkina Faso	1.10	0.90	2.02	–8.42	–0.30	–8.70	10.94	–3.06	7.55	17.00	–1.31	15.46
Gambia	–3.29	–2.38	–5.60	–8.97	–3.72	–12.35	–2.17	–7.08	–9.10	–1.16	0.71	–0.46
Ghana	6.01	1.04	7.11	–0.74	–0.44	–1.18	5.48	–4.18	1.07	–10.21	0.01	–10.20
Guinea	–2.33	4.51	2.08	–1.94	3.03	1.03	–3.12	–0.53	–3.63	–9.14	0.57	–8.62
Guinea Bissau	7.66	2.98	10.87	3.97	1.57	5.60	–0.36	–1.98	–2.33	–3.42	0.71	–2.73
Ivory Coast	–7.71	0.91	–6.87	–10.81	–0.68	–11.42	–14.94	–4.45	–18.72	–26.38	–0.02	–26.40
Liberia	0.74	–0.52	0.22	–1.59	4.72	3.06	–3.80	1.52	–2.34	–5.27	0.71	–4.60
Mali	–5.17	–1.27	–6.38	–9.28	–5.34	–14.12	–0.30	–7.54	–7.82	1.64	–10.44	–8.97
Mauritania	0.20	–40.22	–40.10	5.07	–51.41	–48.95	10.61	–52.69	–47.67	11.17	–53.32	–48.10
Niger	–1.26	37.39	35.66	–10.22	–16.80	–25.30	25.13	–54.66	–43.26	17.66	–62.58	–55.97
Nigeria	0.30	7.89	8.22	–6.44	2.67	–3.94	7.82	–6.40	0.92	5.87	–13.15	–8.06
Senegal	–2.19	0.69	–1.51	–8.06	–5.48	–13.09	–0.33	–12.26	–12.55	2.70	–3.79	–1.19
Sierra Leone	–2.36	0.32	–2.05	–3.70	–1.10	–4.76	–3.80	–4.52	–8.15	–9.76	0.57	–9.24
Togo	–1.70	–7.75	–9.31	–11.80	–9.05	–19.78	–10.76	–12.19	–21.64	–28.60	0.57	–28.19
South Africa	–3.72	5.23	1.59	–7.50	3.78	–4.05	10.31	0.36	10.16	8.61	0.52	7.29
Botswana	1.75	17.08	19.12	–10.91	15.55	2.94	28.10	11.85	43.28	6.20	0.75	7.00
Namibia	–12.91	0.02	–12.90	–22.22	–1.32	–23.24	–1.69	–4.46	–6.08	11.21	0.76	12.05
South Africa	–9.93	1.49	–8.59	–7.65	–0.17	–7.82	–1.37	–3.57	–9.99	–2.74	–0.20	–10.57
Swaziland	6.23	2.34	8.71	10.76	1.05	11.93	16.19	–2.35	13.45	19.75	0.77	20.67

Table 5.10. Impact of alternative climate scenarios on chickpea (percentage deviations from baseline, 2050).

	CSIRO B1			CSIRO A1B			MIROC B1			MIROC A1B		
	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production
Asia	–2.72	4.13	0.64	–1.88	3.15	0.56	–2.36	–0.24	–2.54	2.32	0.99	3.04
India	–0.44	–0.82	–1.26	–1.11	0.01	–1.10	9.76	2.16	12.13	9.90	–0.48	9.36
Afghanistan	1.16	2.21	3.40	1.50	3.22	4.77	–0.03	0.19	0.16	–1.66	–3.53	–5.14
Bangladesh	–5.12	–0.53	–5.63	–6.35	0.39	–5.98	–2.17	–2.19	–4.32	4.08	–2.93	1.03
Iran	–1.18	–10.19	–11.25	9.98	–9.26	–0.21	–11.39	–10.91	–21.06	15.90	–3.91	11.37
Myanmar	0.11	1.79	1.89	–1.71	2.86	1.10	–3.61	–0.21	–3.81	–3.64	–3.77	–7.28
Nepal	–3.58	10.03	6.09	–5.63	11.03	4.78	–4.10	7.77	3.35	–3.81	–3.60	–7.27
Pakistan	–17.18	33.91	10.90	–20.83	18.80	–5.94	–14.20	3.81	–10.93	–6.42	26.40	18.29
China	4.50	–3.35	1.00	9.08	–1.88	7.03	6.89	–2.55	4.17	4.18	–0.25	3.92
Africa												
Northern Africa	–0.88	2.99	2.10	–2.12	5.19	2.90	5.65	4.33	10.92	2.58	–1.93	1.05
Libya	–2.29	2.86	0.50	–2.56	4.23	1.56	–6.38	–0.20	–6.56	–9.70	–5.32	–14.50
Morocco	–0.92	0.76	–0.16	–4.81	12.05	6.66	21.93	27.42	55.36	17.93	22.35	44.28
Sudan	2.65	5.40	8.18	0.63	0.99	1.62	24.92	–5.16	18.48	21.77	–15.76	2.58
Tunisia	–4.29	3.25	–1.18	–3.43	4.69	1.10	–7.44	0.55	–6.93	–10.12	–4.33	–14.01
Eastern Africa	8.94	–0.47	8.17	7.50	2.07	9.27	15.54	–2.20	12.97	16.73	–3.60	13.14
Eritrea	3.94	3.05	7.11	3.78	4.29	8.23	19.19	0.37	19.63	16.99	–4.86	11.30
Ethiopia	19.98	–12.43	5.06	22.08	–13.91	5.10	24.70	–16.84	3.71	20.81	–5.94	13.64
Kenya	8.62	4.94	13.98	4.30	15.69	20.65	20.93	12.50	36.05	39.66	9.19	52.49
Malawi	9.32	0.30	9.65	9.66	1.87	11.71	10.68	–2.90	7.48	3.78	–6.12	–2.58
Tanzania	6.72	2.13	8.99	7.48	3.70	11.46	14.22	–1.87	12.09	15.02	–7.02	6.94
Uganda	5.07	–0.80	4.23	–2.30	0.79	–1.53	3.50	–4.50	–1.16	4.14	–6.83	–2.97

Table 5.11 Impact of alternative climate scenarios on pigeonpea (percentage deviations from baseline, 2050).

	CSIRO B1			CSIRO A1B			MIROC B1			MIROC A1B		
	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production
Asia	–2.34	2.67	0.25	–3.78	3.53	–0.42	–0.42	0.50	0.06	1.84	–2.11	–0.23
Bangladesh	–5.41	–0.49	–5.87	–6.66	0.36	–6.32	–2.89	–3.38	–6.18	4.22	–2.41	1.71
India	–0.50	–0.76	–1.26	–1.12	–0.04	–1.15	9.47	0.58	10.11	10.33	0.21	10.56
Myanmar	0.14	1.85	1.98	–1.70	2.82	1.08	–3.84	–1.56	–5.35	–3.52	–3.19	–6.60
Nepal	–3.56	10.08	6.16	–5.64	10.99	4.73	–4.44	6.37	1.65	–3.66	–3.05	–6.60
Africa	10.92	2.75	14.12	8.82	6.02	15.49	12.62	–1.07	11.58	15.34	–2.60	12.84
Burundi	23.71	6.83	32.16	23.95	8.40	34.36	22.89	0.40	23.38	21.68	–5.95	14.43
Kenya	9.57	5.03	15.08	5.19	15.58	21.57	13.06	9.91	24.26	31.29	10.22	44.71
Malawi	9.34	0.39	9.77	9.64	1.82	11.63	10.16	–4.89	4.78	3.99	–5.27	–1.49
Tanzania	6.73	2.23	9.11	7.53	3.64	11.44	13.85	–4.08	9.21	15.45	–6.09	8.42
Uganda	5.24	–0.74	4.46	–2.23	0.69	–1.55	3.15	–6.68	–3.74	4.27	–5.90	–1.88

Table 5.12. Percentage deviation from baseline prices, 2050.

	Millets	Sorghum	Chickpea	Pigeonpea	Groundnut
Baseline	364.16	152.21	839.73	647.80	738.82
CSIRO B1	5.25	4.34	8.75	8.89	14.75
CSIRO A1B	5.91	5.14	11.59	11.50	13.14
MIROC B1	4.51	5.00	5.00	1.97	8.54
MIROC A1B	8.71	7.26	–5.59	–4.37	4.90

6 Evaluating Adaptation Options at Crop Level for Climate Change in the Tropics of South Asia and West Africa

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Abstract

Crop level adaptations to present and future climate are indispensable to farmers because their livelihood depends on crop-based income. Hence, quantifying impact and adaptation options at the field level is yet another important step in adaptation planning at farm-level. This chapter analyses the impact and plausible adaptations for the major crops of the semi-arid tropical region with illustrations from the selected study sites in Asia and Africa. The calibrated crop simulation models that simulate physical and physiological processes of plant growth were used for this purpose. Finally, the chapter evaluates plausible agronomic and genetic options that have the potential to adapt to climate changes in the tropical environments.

6.1 Introduction

An increasing concentration of greenhouse gases (GHGs) in the atmosphere owing to anthropogenic activities is warming the globe. According to the Intergovernmental Panel on Climate change (IPCC, 2013) the global mean surface temperatures are projected to be in the range of 1.4°C to 3.1°C by the end of century (2081–2100 relative to 1986–2005) as per the RCP6.0 emission scenario (a medium stabilization scenario after 2100). This is causing climate change in terms of increased air temperature and increased variability in the amount, distribution and intensity of rainfall depending upon the location on the globe. These climate change factors are progressively changing the agroclimatic characteristics of the environments where food crops are currently grown. With climate change in future, the productivity of crops, especially in the tropical regions, may be adversely affected, thus threatening food security in these regions, whereas in some high latitude regions it may improve crop growth conditions for higher productivity.

Diverging effects of rising GHG concentrations are: (i) direct effects of climate change; (ii) indirect effects of climate change; and (iii) non-climatic impacts related to GHG emissions (Gornall *et al*., 2010). Direct effects include change in mean climate (higher temperatures, changing precipitation patterns) and increased climate variability and extremes (extreme temperatures and heat waves, drought, heavy rainfall and flooding, tropical or heavy storms). Indirect effects of

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climate change are change in water availability, change in length of growing season, climate-induced high runoff and soil erosion, mean sea level rise and changed scenario of pests and diseases. The non-climate impacts related to GHG emissions are CO_2 fertilization and effects of ozone on vegetation. Because climate is the primary determinant of agricultural productivity, agricultural production is most sensitive and vulnerable to climate change (Watson *et al.*, 1996). But it is also contributing about one-third to total GHG emissions, mainly through livestock, rice production, nitrogen fertilization and tropical deforestation (Lotze-Campen, 2011).

Agriculture currently accounts for 5% of world economic output, employs 22% of the global workforce and occupies 40% of total land area. In developing countries about 70% of the population lives in rural areas, where agriculture is the largest supporter of livelihoods. In many developing countries the economy is heavily depending on agriculture. The sector accounts for 40% of gross domestic product (GDP) in Africa and 28% in South Asia.

In future, however, agriculture will have to compete for scarce land and water resources with growing urban areas and industrial production (Lotze-Campen, 2011). Most developing countries are located in the lower latitudes (tropical arid and semi-arid regions), which are already characterized by highly volatile climatic conditions. These countries, being dependent on agriculture, will be strongly affected by climate change and have lower adaptive capacity. Non-climatic stresses such as population, poverty, unequal access to resources, etc., increase vulnerability to climate change by reducing the adaptive capacity of the system. Creating more options for climate change adaptation and improving the adaptive capacity in the agricultural sector will be crucial for improving food security and preventing an increase in global inequality in living standards in the future (Lotze-Campen, 2011).

In this chapter we have focused on the processes and impacts of projected climate change on crop production, regional differences in climate change in South Asia and West Africa, a review of possible adaptation options at plant or crop level, and evaluation and prioritization of adaptation options that will most likely help in coping with climate change in different regions of South Asia and West Africa. The socio-economic aspects of adaptation to cope with climate change have been discussed in other chapters of this book.

6.2 How Does Climate Change Impact Crop Production?

6.2.1 High temperatures

High temperatures affect the growth and development of crops, thus influencing potential yields. High temperatures drive shorter life cycles, resulting in less seasonal photosynthesis, a shorter reproductive phase and thus lower yield. Vegetative development is accelerated in cereals with increasing temperature, but it is the dramatically shorter grain-filling period with rising temperature that has major consequences for yield. In photoperiod-responsive plants, the timing of the reproductive stages is determined by an interactive response to temperature and photoperiod. Whereas these relationships are reasonably well understood in the suboptimal through to optimal temperature range, this understanding does not extend into the supra-optimal temperature range, but clearly understanding how these higher temperatures will interact with photoperiod to determine flowering time will become increasingly important as climate change progresses (Craufurd and Wheeler, 2009).

Higher than optimal temperatures during reproductive stages have impacts beyond shortening the duration of grain filling. High-temperature stress that affects any of the reproductive processes, including pollen viability, female gametogenesis, pollen–pistil interaction, fertilization and grain formation, makes it perhaps the most critical stage of growth in determining the response of crop yield to high temperatures. High-temperature stress has been shown to affect both pollen production and pollen viability.

It is, however, the pollen viability above the optimum temperature that affects the quantity and quality of yield via a range of mechanisms (Hedhly *et al*., 2008). Within a permissive range, warming temperatures accelerate both the rate of pollen tube growth as well as stigma and ovule development, thus maintaining the male–female synchrony necessary for successful seed set. Under high-temperature stress, however, this synchrony can be lost, leading to lower fertility and yield reduction (Hedhly *et al*., 2008). Another type of loss of synchrony that can occur due to global change and have consequences for yield is in insect-pollinated crops, where alterations to the annual temperature cycle can uncouple insect life cycles with crop-flowering phenology (Memmott *et al*., 2007).

In the seasonally arid and tropical regions, where temperatures are already close to the physiological maxima for crops, higher temperatures may be more immediately detrimental, increasing the heat stress on crops and water loss by evaporation. A 2°C local warming in the mid-latitudes could increase wheat production by nearly 10%, whereas at low latitudes the same amount of warming may decrease yields by nearly the same amount (Gornall *et al*., 2010). Different crops show different sensitivities to warming. By fitting statistical relationships between growing season temperature, precipitation and global average yield for six major crops, Lobell and Field (2007) estimated that warming since 1981 has resulted in annual combined losses of 40 million tonnes or US$5 billion.

6.2.2 Changes in precipitation

Water is vital to plant growth so varying precipitation patterns have a significant impact on agriculture. As more than 80% of total agriculture is rainfed, projections of future precipitation changes often influence the magnitude and direction of climate impacts on crop production (Tubiello *et al*., 2002; Reilly *et al*., 2003). The impact of global warming on regional precipitation is difficult to predict owing to strong dependencies on changes in atmospheric circulation, although there is increasing confidence in projections of a general increase in high-latitude precipitation, especially in winter, and an overall decrease in many parts of the tropics and subtropics (IPCC, 2007; IPCC, 2013). Precipitation is not the only influence on water availability. Increasing evaporative demand owing to rising temperatures and longer growing seasons at high latitudes could increase crop irrigation requirements globally by between 5% and 20%, or possibly more, by the 2070s or 2080s, but with large regional variations. South-east Asian irrigation requirements could increase by 15% (Döll, 2002).

6.2.3 Climate variability and extreme weather events

Although change in long-term mean climate will have significance for global food production and may require ongoing adaptation, greater risks to food security may be posed by changes in year-to-year variability and extreme weather events. Historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events (Kumar *et al*., 2004; Sivakumar *et al*., 2005). The following aspects of extreme weather could drastically affect crop production and, therefore, human livelihoods.

Extreme temperatures and heat waves

Meteorological records and future projections suggest that heat waves became more frequent over the 20th century (IPCC, 2013). Changes in short-term temperature extremes can be critical, especially if they coincide with key stages of crop development. Only a few days of extreme temperature (greater than 32°C) at the flowering stage of many crops can drastically reduce yield (Wheeler *et al*., 2000). Reviews of the literature (Porter and Gawith, 1999; Wheeler *et al*., 2000) suggest that temperature thresholds are well defined and highly conserved between species, especially for processes such as anthesis and grain filling. Although groundnut is grown in semi-arid regions that regularly experience temperatures of 40°C, if after flowering the plants are exposed to temperatures exceeding 42°C, even for short periods, yield can be drastically reduced (Vara Prasad *et al.*, 2003). Similarly, increases in temperature above 29°C for maize, 30°C for soybean and 32°C for cotton negatively impacted the yields in the USA (Gornall *et al.*, 2010).

Increased frequency of drought

Globally, the areas sown for the major crops of barley, maize, rice, sorghum, soybean and wheat have all seen an increase in the percentage of area affected by drought (IPCC, 2007). A comparison of climate model simulations with observed data suggests that anthropogenic increases in greenhouse gas and aerosol concentrations have made a detectable contribution to the observed drying trend in climate (Burke *et al.*, 2006). Li *et al.* (2009) defined a yield reduction rate (YRR) for a crop as the ratio of actual reduced yield due to climate variability to the long-term trend yield. Using national-scale data for the four major grains (barley, maize, rice and wheat), Li *et al.* (2009) suggested that 60–75% of observed YRRs can be explained by a linear relationship between YRR and a drought risk index based on the Palmer Drought Severity Index (Palmer, 1965). By assuming the linear relationship between the drought risk index and YRR holds into the future, Li *et al.* (2009) estimated that drought related yield reductions would increase by more than 50% by 2050 and almost 90% by 2100 for the major crops.

Heavy rainfall and flooding

Heavy rainfall events leading to flooding can wipe out entire crops over wide areas, and excess water can also lead to other impacts including soil water logging, anaerobic conditions and reduced plant growth. Indirect impacts include delayed farming operations. In a study looking at the impacts of current climate variability, Kettlewell *et al.* (1999) showed that heavy rainfall in August was linked to lower grain quality, which leads to sprouting of the grain in the ear and fungal disease infections of the wheat grain. This was shown to affect the quality of the subsequent products such that it influenced the amount of milling wheat that was exported from the UK. The proportion of total rain falling in heavy rainfall events seems to be increasing and this trend is expected to continue as the climate continues to warm. Using daily rainfall data from 1951 to 2000, Goswami *et al.* (2006) also showed a significant rising trend in the frequency and magnitude of extreme rainfall events over central India during the monsoon season, suggesting enhanced risks associated with extreme rainfall over India in the coming decades.

Tropical or heavy storms

Tropical cyclone frequency is likely to decrease or remain unchanged over the 21st century, whereas intensity (i.e. maximum wind speed and rainfall rates) is likely to increase (IPCC, 2013). There is, however, limited consensus among the models on the regional variations in tropical cyclone frequency. Both societal and economic implications of tropical cyclones can be high, particularly in developing countries with high population growth rates in vulnerable tropical and subtropical regions. This is particularly the case in the North Indian Ocean, where the most vulnerable people live in the river deltas of Myanmar, Bangladesh, India and Pakistan; here population growth has resulted in increased farming in coastal regions most at risk from flooding (Webster, 2008).

Heavy rains, droughts and high temperatures also cause high runoff and soil erosion and loss of nutrients from the soils. Nutrient conservation is affected by warmer temperatures because high temperatures are likely to increase natural decomposition of organic matter because of a stimulation of microbial activity. If mineralization exceeds uptake, nutrient leaching will be the consequence (Niklaus, 2007). Increased frequency of droughts further intensifies erosive losses as plant biomass and its positive effects on soils are reduced (Nearing *et al.*, 2004; Niklaus, 2007).

6.2.4 Change in length of growing period

Length of growing period (LGP) at any location is an important indicator of the yield potential of that location and determines the suitability of contrasting management practices and maturity length of crop types and cultivars. The LGP is defined as the number of days in any given rainfall season when there is sufficient water stored in the soil profile to support crop growth. On the basis of the global analysis of LGP with and without climate change, Cooper *et al*. (2009) estimated that the net semi-arid tropical area (SAT) would increase with climate change. Most of the SAT area would be lost from the driest margins to arid zone through LGPs becoming short, or gained on their wetter margins from sub-humid regions through the reduction in current LGPs in those zones. They also expected that the greater the aridity and warming in the climate change scenarios, the more pronounced is the impact on changes in the distribution of the SAT. The changes in the distribution of SAT will affect many millions of families worldwide who rely on rainfed agriculture for their livelihoods. This will have a major effect on the current farming systems of the SAT region in future with climate change. In a similar study, Kesava Rao *et al*. (2013) estimated a 3.45 million hectare increase in SAT area in India with climate change from 1971–1990 to 1991–2004.

6.2.5 Pests and diseases

Temperature rise and elevated CO_2 concentration could increase plant damage from pests in future decades, although only a few quantitative analyses exist to date (Easterling *et al*., 2007; Ziska and Runion, 2007). Pests such as aphids (Newman, 2004) and weevil larvae (Staley and Johnson, 2008) respond positively to elevated CO_2. Increased temperatures also reduced the overwintering mortality of aphids enabling earlier and potentially more widespread dispersion (Zhou *et al*., 1995). In sub-Saharan Africa, migration patterns of locusts may be influenced by rainfall patterns (Cheke and Tratalos, 2007) and thus climate change may reshape the impacts of this devastating pest. Pathogens and disease may also be affected by a changing climate. This may be through impacts of warming or drought on the resistance of crops to specific diseases and through the increased pathogenicity of organisms by mutation induced by environmental stress (Gregory *et al*., 2009). Over the next 10–20 years, disease affecting oilseed rape could increase in severity within its existing range as well as spread to more northern regions where at present it is not observed (Evans *et al*., 2008). Changes in climate variability may also be significant, affecting the predictability and amplitude of outbreaks (Gornall *et al*., 2010).

6.2.6 Increase in atmospheric carbon dioxide

Increasing atmospheric carbon dioxide (CO_2) concentrations can directly affect plant physiological processes of photosynthesis and transpiration (Field *et al*., 1995). The CO_2 physiological response varies between C3 and C4 plants because of their different photosynthesis pathways. Experiments under idealized conditions show that a doubling of atmospheric CO_2 concentration increases photosynthesis by 30–50% in C3 plant species and 10–25% in C4 species (Ainsworth and Long, 2005). Crop yield increase is lower than the photosynthetic response; increases of atmospheric CO_2 to 550 ppm would on average increase C3 crop yields by 10–20% and C4 crop yields by 0–10% (Long *et al*., 2004; Ainsworth and Long, 2005). Despite the potential positive effects on yield quantities, elevated CO_2 may, however, be detrimental to yield quality of certain crops. For example, elevated CO_2 is detrimental to wheat flour quality through reductions in protein content (Sinclair *et al*., 2000). Global-scale comparisons of the impacts of CO_2 fertilization with those of changes in mean climate (Parry *et al*., 2004; Nelson *et al*., 2009) show that the strength of CO_2 fertilization effects is a critical factor in determining whether global-scale yields are projected to increase or decrease. In fact without CO_2 fertilization, all regions are projected to experience a loss in productivity owing to climate change by 2050 (Parry *et al.*, 2004; Nelson *et al.*, 2009). Estimates suggest, however, that stabilizing CO_2 concentrations at 550 ppm would significantly reduce production losses by the end of the century (Arnell *et al.*, 2002; Tubiello and Fischer, 2006). For all species higher water-use efficiencies and greater root densities under elevated CO_2 in field systems may, in some cases, alleviate drought pressures, yet their large-scale implications are not well understood (Wullschleger *et al.*, 2002; Centritto, 2005). This could offset some of the expected warming-induced increase in evaporative demand, thus easing the pressure for more irrigation water (Gornall *et al.*, 2010).

6.2.7 Ozone

Ozone is a major secondary air-pollutant, which at current concentrations has been shown to have significant negative impacts on crop yields (Van Dingenen *et al.*, 2009). Whereas in North America and Europe emissions of ozone precursors are decreasing, in other regions of the world, especially Asia, they are increasing rapidly (Van Dingenen *et al.*, 2009). Higher ozone concentration reduces photosynthetic rates and other important physiological functions, which in turn reduce final yield and yield quality (Mills *et al.*, 2009; Ainsworth and McGrath, 2010). The interactive effects of ozone with other environmental factors, such as CO_2, temperature, moisture and light, are important but not well understood.

6.3 Regional Differences in Climate Change

Warming is observed over the entire globe, but with significant regional and seasonal variations. In Africa, warming is very likely to be larger than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moist tropics. The differences in near-surface temperature by the end of the century (2080 to 2099) in the MMD-A1B (multi-model data-A1B) model projections, averaged over the West African, East African and South African sub-regions, are provided in Table 6.1. In all three regions and in all seasons, the median temperature increase lies between 3°C and 4°C. There is much less certainty about changes in rainfall in the West Africa region. However, Sivakumar *et al.* (2005) analysed the past rainfall data of several locations in Niger and have shown a significant decline in rainfall over the past years.

In Asia, warming is likely to be well above the global mean in eastern Asia and South Asia, and similar to the global mean in

Table 6.1. Regional MMD-A1B model projections for climate change in Africa and Asia by the end of the 21st century. The data presented are annual values of minimum, maximum, 25%, 50% (median) and 75% quartile values among the 21 models (IPCC, 2007).

	Temperature responses (°C)					Rainfall response (%)				
Region	Min	25%	50%	75%	Max	Min	25%	50%	75%	Max
West Africa	1.8	2.7	3.3	3.6	4.7	–9	–2	2	7	13
East Africa	1.8	2.5	3.2	3.4	4.3	–3	2	7	11	25
Southern Africa	1.9	2.9	3.4	3.7	4.8	–12	–9	–4	2	6
East Asia	2.3	2.8	3.3	4.1	4.9	2	4	9	14	20
Southern Asia	2.0	2.7	3.3	3.6	4.7	–15	4	11	15	20
South-east Asia	1.5	2.2	2.5	3.0	3.7	–2	3	7	8	15

South-east Asia. Precipitation in winter is likely to increase in eastern Asia and the southern parts of South-east Asia. Precipitation in summer is likely to increase in East Asia, South Asia and most of South-east Asia. It is very likely that heat waves/hot spells in summer will be of longer duration, more intense and more frequent in East Asia. Fewer very cold days are very likely in East Asia and South Asia. There is very likely to be an increase in the frequency of intense precipitation events in parts of South Asia and in East Asia. Extreme rainfall and winds associated with tropical cyclones are likely to increase in East Asia, South-east Asia and South Asia.

In South Asia, the MMD-A1B model projections show a median increase of 3.3°C (Table 6.1) in annual mean temperature by the end of the 21st century. Studies based on earlier Atmosphere–Ocean Global Circulation Model (AOGCM) simulations (Douville *et al*., 2000; Lal and Harasawa, 2001; Lal *et al*., 2001; Rupa Kumar and Ashrit, 2001; Ashrit *et al*., 2003) support this picture. Downscaled projections using the Hadley Centre Regional Model (HadRM2) indicate future increases in extreme daily maximum and minimum temperatures throughout South Asia due to the increase in greenhouse gas concentrations. This projected increase is of the order of 2°C to 4°C in the mid-21st century under the IPCC Scenario IS92a in both minimum and maximum temperatures (Kumar *et al*., 2003). Results from a more recent regional climate model (RCM), PRECIS, indicate that the night temperatures will increase faster than the day temperatures, with the implication that cold extremes are very likely to be less severe in the future (Rupa Kumar *et al*., 2006). Most of the MMD-A1B models project a decrease in precipitation in DJF (December, January and February, the dry season), and an increase during the rest of the year. The median change is 11% by the end of the 21st century (Table 6.1), and seasonally is –5% in DJF and 11% in JJA (June, July and August), with a large inter-model spread. This qualitative agreement on increasing precipitation for most of the year is also supported by the AOGCM simulations. The HadRM2 RCM shows an overall decrease by up to 15 days in the annual number of rainy days over a large part of South Asia, under the IS92a scenario in the 2050s, but with an increase in the precipitation intensity as well as extreme precipitation (Kumar *et al*., 2003). Simulations with the PRECIS RCM also project substantial increases in extreme precipitation over a large area, particularly over the west coast of India and west central India (Rupa Kumar *et al*., 2006). On the basis of regional HadRM2 simulations, Unnikrishnan *et al*. (2006) reported increases in the frequency as well as intensities of tropical cyclones in the 2050s under the IS92 scenario in the Bay of Bengal, which will cause more heavy precipitation in the surrounding coastal regions of South Asia, during both south-west and north-east monsoon seasons.

6.4 Impacts on Tropical Crops

Long-term impacts of climate change on agricultural productivity are not expected to be geographically uniform. Although a small increase in yields and production could occur with climate change in certain high latitude locations, there is a serious threat to crop productivity in the tropical regions that are already food insecure. Some of these regions are sub-Saharan Africa or South Asia where most of the population increase will take place in future (Sultan, 2012). For example, it is estimated that by 2050 food needs will more than quintuple in Africa and more than double in Asia (Collomb, 1999). Therefore, the potential impact of climate change on crop productivity is an additional strain on the global food system, which is already facing the difficult challenge of increasing food production to feed a projected 9 billion people by 2050 with changing consumption patterns and growing scarcity of water and land (Beddington, 2010). Better knowledge of climate change impacts on crop productivity in the vulnerable regions is crucial to support adaptation strategies and inform policies and that may counteract the adverse effects (Sultan, 2012). There have been several studies in the past in Asia and Africa to assess the impact of climate change on crop production. Most of the studies have been conducted on major food crops like rice, wheat and maize with much less work on the rainfed crops like sorghum, millets, groundnut and other grain legumes of the semi-arid tropics.

Lobell *et al*. (2008) estimated the probability distribution of per cent yield change among major crops across most of Africa and South and South-east Asia compared with the baseline (1980–2000) and projections for 2020–2040, assuming an increase of 1°C in temperature between 1980–2000 and 2020–2040 across most regions. They predicted significant negative impacts of climate change on food security that could occur as early as 2030 for several crops in these regions. Although there is a growing literature on the impact of climate change on crop productivity in tropical regions, it is difficult to provide a consistent assessment of future yield changes because of large uncertainties in regional climate change projections, in the response of crops to environmental change (rainfall, temperature, CO_2 concentration), in the coupling between climate models and crop productivity functions, and in the adaptation of agricultural systems to progressive climate change (Challinor *et al*., 2007; Roudier *et al*., 2011). A rigorous multi-ensemble approach, with varying climate models, emissions scenarios, crop models and downscaling techniques, as recommended by Challinor *et al*. (2007), would enable a move towards a more complete sampling of uncertainty in crop yield projections. In that sense, coordinated modelling experiments such as the ones conducted throughout the Agricultural Model Inter-comparison and Improvement Project (AgMIP; www.agmip.org/) are likely to improve substantially the characterization of the threat of crop yield losses and food insecurity due to climate change (Sultan, 2012).

A study by Knox *et al*. (2012) is among the first to provide robust evidence of how climate change will impact productivity of major crops in Africa and South Asia. The analysis was conducted for eight food and commodity crops (rice, wheat, maize, sorghum, millets, cassava, yam and sugarcane), which collectively account for over 80% of total crop production in Africa and South Asia (FAO, 2010). Using a meta-analysis of different independent published studies, Knox *et al*. (2012) show a consistent yield loss by the 2050s of major crops (wheat, maize, sorghum and millets) in both regions. They estimate that mean yield change for all crops is –8% by the 2050s with strong variations among crops and regions. Across Africa, mean yield changes of –17% (wheat), –5% (maize), –15% (sorghum) and –10% (millets) and across South Asia of –16% (maize) and –11% (sorghum) were estimated. No mean change in yield was detected for rice. Evidence of crop yield impact in Africa and South Asia was robust for wheat, maize, sorghum and millets, and either inconclusive, absent or contradictory for rice, cassava and sugarcane.

Such robust evidence of future yield change in Africa and South Asia can be surprising in regards to the diverging projections in a warmer climate of summer monsoon rainfall, the primary driver for rainfed crop productivity in the region, especially in West Africa where some studies make projections of wetter conditions and some predict more frequent droughts (Druyan, 2011). This is because of the adverse role of higher temperatures in shortening the crop-cycle duration and increasing evapotranspiration demand and thus reducing crop yields, irrespective of rainfall changes (Schlenker and Lobell, 2010; Roudier *et al*., 2011; Berg *et al*., 2012). Potential wetter conditions or elevated CO_2 concentrations hardly counteract the adverse effect of higher temperatures (Sultan, 2012).

In spite of the threat of crop yield losses in a warmer climate, developing countries in the tropics have the potential to more than offset such adverse impacts by implementing more intensive agricultural practices and adapting agriculture to climate and environmental change (Berg *et al*., 2012). Indeed, Africa and to a lesser extent South Asia are among the only regions of the world where there is an untapped potential for raising agricultural productivity because poor soil fertility and low input levels, combined with extensive agricultural practices, contribute to a large gap between actual and potential yields (Licker *et al*., 2010; Sultan, 2012).

6.5 Adaptation Measures

The pervasiveness of climate impacts on food security and production means that some level of adaptation of food systems to climate change will be necessary. Adaptation is defined as an 'adjustment in natural or human systems in response to actual or expected stimuli or their effects, which moderates harm or exploits beneficial opportunities' (Christensen *et al*., 2007). Adaptation response can be autonomous or planned. Autonomous adaptations are those that take place without the directed intervention of a public agency and assuming efficient markets (Howden *et al*., 2010). Planned or policy-driven adaptation is the result of a deliberate policy decision by a public agency based on an awareness that conditions are about to change or have changed and that action is required to minimize the losses or benefit from opportunities (Pittock and Jones, 2000). According to Howden *et al*. (2010), autonomous adaptations are incremental changes in the existing system including the ongoing implementation of extant knowledge and technology in response to the changes in climate experienced. They include coping responses and are reactive in nature. Planned adaptations are proactive and can either adjust the broader system or transform it. Adaptations can occur at a range of scales from field to policy. There is an increasing recognition in the literature that, while many adaptation actions are local and build on past climate risk management experience, effective adaptation will often require changes in institutional arrangements and policies to strengthen the conditions favourable for effective adaptation, including investment in new technologies, infrastructure, information and engagement processes.

Adaptation strategies often contain both social and technical elements that sometimes act independently of each other and at other times interact. Among social adaptation strategies are maximization of family labour use, including generating remittances by temporary or permanent migration; diversification into non-agricultural enterprise; development of social protection schemes and employment schemes; crop and livestock insurance; and realization of collective action and community-based empowerment effort. Resilience, in the context of social elements mentioned above, is strongly associated with diversification of income-generating opportunities that reduce exposure to livelihood shocks from climatic and non-climatic factors. In this chapter we have primarily focused on the crop-level adaptation measures, although other types of adaptation measures are also important to the farming community to adapt to the climate change. Crop-level adaptation measures include agronomic, land and water management and genetic improvement measures to enhance and sustain crop yields under climate change conditions. Tables 6.2 and 6.3 list these adaptation measures and the climate change problem these measures address to cope with climate change, singly or in combination with other measures.

Changing planting dates is frequently identified as an option for cereals and oilseeds provided there is not an increase in drought at the end of the growing season (Table 6.2). This may be necessitated owing to high temperatures and/or low rainfall with climate change during the early part of the growing season in the semi-arid areas or the possibility of extended growing seasons because of higher temperatures increasing growth in cooler months (Tingem and Rivington, 2009; Travasso *et al*., 2009; Laux *et al*., 2010; Tao and Zhang, 2010; Van de Geisen *et al*., 2010). Aggregated across studies, changing planting dates may increase yields by a median of 3–17% but with substantial variation.

Optimization of crop varieties and planting schedules seem to be effective adaptations, increasing yields by up to 23% compared with current management when aggregated across studies. This flexibility in planting dates and varieties according to seasonal conditions could be increasingly important with ongoing climate change (Deressa *et al*., 2009) and especially in dealing with projections of increased climate variability. Approaches that integrate climate forecasts at a range of scales in some cases are able to better inform crop risk

Table 6.2. Agronomic and land and water management measures for adapting to climate change.

Adaptation measures	Climate parameters or related issues being addressed	Reference
Adjustment in sowing and harvesting dates	Increase in temperature, change in rainfall, change in length of growing period (LGP)	Tingem and Rivington, 2009; Travasso *et al*., 2009; Laux *et al*., 2010; Tao and Zang, 2010; Van de Geisen *et al*., 2010
Changing plant population and nutrient management	Changes in rainfall and LGP, increased rainfall variability and drought	Howden *et al*., 2007
Crop substitution to less water-intensive crops	Changes in rainfall and LGP, increased drought	Howden *et al*., 2007
Site-specific cropping systems and patterns and their management	Changes in rainfall and LGP, increases in rainfall variability, drought, soil salinity or water logging, and increased severity of pests and diseases	Butt *et al*., 2005
Greater diversity of crops and cultivars	Increase in rainfall variability or extreme weather events, increased severity of pests and diseases	Butt *et al*., 2005; Cooper *et al*., 2009; Ebi *et al*., 2011
Conservation agriculture-surface crop residues, no till and rotations	Increases in temperature, rainfall variability, droughts or extreme weather events, runoff, soil erosion and land degradation	Lioubimtseva and Henebry 2009; Ebi *et al*., 2011
Diversifying production systems	Increase in rainfall variability or extreme weather events, increased severity of pests and diseases	Verchot *et al*., 2007; Lioubimtseva and Henebry, 2009; Thornton *et al*., 2010; Ebi *et al*., 2011.
Shelter belts for microclimate modification	Increases in temperature, drought or extreme weather events, and severity of pests and diseases	Aggarwal, 2008
Climate forecasts to reduce production risks	Increases in rainfall variability, droughts, extreme weather events or water logging, and severity of pests and diseases	Howden *et al*., 2007; Cooper *et al*., 2009; Baethgen, 2010
Soil and water conservation measures and prevention of water logging	Increase in rainfall variability, droughts or extreme weather events, increased runoff and soil erosion, water logging and land degradation	Howden *et al*., 2007; Aggarwal, 2008; Thomas, 2008; Cooper *et al*., 2009; Ebi *et al*., 2011
Water harvesting, drip irrigation and judicious use of water	Change in rainfall, increases in rainfall variability, droughts or extreme weather events, increased runoff and soil erosion, increased water logging	Howden *et al*., 2007; Aggarwal, 2008; Thomas, 2008; Deryng *et al*., 2011

management (Cooper *et al*., 2009; Baethgen, 2010), although such forecasts are not always usable or useful (Dilling and Lemos, 2011).

Diversification of activities is another climate adaptation option for cropping systems (Lioubimtseva and Henebry, 2009; Thornton *et al*., 2010). Diversification of activities often incorporates higher value activities or those that increase efficiency of a limited resource such as through increased water use efficiency (Thomas, 2008) or to reduce risk (Seo, 2010). In some cases, increased diversification outside of agriculture may be favoured

(Mary and Majule, 2009; Mertz *et al*., 2009). The above adaptations, either singly or in combination, could significantly reduce negative impacts of climate change or take advantage of positive changes.

For enhanced storage and access to irrigation water, more efficient water delivery systems, improved irrigation technologies such as deficit irrigation, more effective water harvesting, agronomy that increases soil water retention through practices such as minimum tillage and canopy management, agroforestry, increase in soil carbon and more effective decision support (Verchot *et al*., 2007; Lioubimtseva and Henebry, 2009; Luo *et al*., 2009; Piao *et al*., 2010) are among many other possible adaptations (Table 6.2). Crop adaptations can lead to moderate yield benefits (mean of 10 to 20%) under persistently drier conditions (Deryng *et al*., 2011) and irrigation optimization for a changed climate can increase yields by a median of 3.2%, as well as having a range of other beneficial effects.

Improving cultivar tolerance to high temperature is a frequently identified adaptation for almost all crops and environments worldwide (Table 6.3) because high temperatures are known to reduce both yield and quality (Challinor *et al*., 2009; Luo *et al*., 2009). Noting that a new cultivar usually takes between 8 and 20 years to deliver, it is important to be selecting cultivars for expected future climate and atmospheric conditions (Ziska *et al*., 2012). Improving gene conservation and access to extensive gene banks could facilitate the development of cultivars with appropriate thermal time and thermal tolerance characteristics (Mercer *et al*., 2008) as well as to take advantage of increasing atmospheric CO_2 concentrations (Ziska *et al*., 2012) and respond to changing pest, disease and weed threats with these developments needing to be integrated with *in situ* conservation of local varieties (IAASTD, 2009). Similarly, the prospect of increasing drought conditions in many cropping regions of the world raises the need for breeding additional drought-tolerant crop varieties (Mutekwa, 2009; Tao and Zhang, 2011) (Table 6.3).

To quantify the benefits of adaptation, a meta-analysis of recent crop adaptation studies has been undertaken for wheat, rice and maize (IPPC, 2013, Working Group II, AR5, Chapter 7). The analysis indicated that the average benefit (the yield difference between the adapted and non-adapted cases) of adapting crop management is equivalent to about 15 to 18% of current yields. This response is, however, extremely variable, ranging from negligible benefit from adaptation to very substantial. The

Table 6.3. Genetic measures for adapting to climate change.

Adaptation strategies	Climate change and related problem being addressed	Reference
Short or longer duration cultivar	Change in rainfall, change in LGP, increased drought	Howden *et al*., 2007; Aggarwal, 2008; Thomas, 2008
Heat-tolerant varieties	Increase in temperature	Butt *et al*. 2005; Challinor *et al*., 2007; Ebi *et al*., 2011
Drought-tolerant varieties	Decrease in rainfall, increase in rainfall variability, change in LGP, increased drought	Challinor *et al*., 2007; Aggarwal, 2008; Tao and Zhang, 2011
Salinity-tolerant cultivars	Increased soil salinity	Reddy *et al*., 2010
Pest- and disease-tolerant cultivars	Increased severity of pests and diseases	Howden *et al*., 2007; Aggarwal, 2008
Integrated pest, disease and weed management	Increased severity of pests and diseases	Howden *et al*., 2007; Aggarwal, 2008
CO_2 responsive cultivars for higher yield	To take advantage of increased CO_2	Ziska *et al*., 2012

responses are dissimilar among wheat, maize and rice, with temperate wheat and tropical rice showing greater benefits of adaptation. The responses also differ markedly between adaptation management options. For example, when aggregated over studies, cultivar adaptation (23%) and altering planting date in combination with other adaptations (3 to 17%) provide on average more benefit than optimizing irrigation (3.2%) or fertilization (1%) to the new climatic conditions. These limits to yield improvements from agronomic adaptation and the increasingly overall negative crop yield impact with ongoing climate change mean a substantial challenge in ensuring increases in crop production of 14% per decade given a population of 9 billion people in 2050. This could be especially so for tropical wheat and maize where impacts from increases in temperature of more than 3°C may more than offset benefits from agronomic adaptations. Indigenous knowledge is an important resource in climate risk management and is important for food security in many parts of the world. Climate changes may be reducing reliance on indigenous knowledge in some locations but also some policies and regulation may be limiting the contribution that indigenous knowledge can make to effective climate adaptation. Forthcoming studies should examine the impact of proposed adaptations when employed in the current climate. In this way management changes that are beneficial in a range of environments can be separated from management changes that are specifically targeted at climate change.

Some autonomous adaptations, such as shifting planting dates, modifying crop rotations or the uptake of pre-existing crop varieties will help offset some negative impacts of climate change. It is reported, however, that the greatest benefits in food-insecure regions are likely to arise from more expensive adaptation measures including the development of new crop varieties and uptake of new technologies, including, for example, the expansion of irrigation infrastructure (Lobell *et al.*, 2008). These will require substantial investments by farmers, governments and development agencies. It is thus vital that any policy decisions to support their implementation, particularly aid investments, are informed by a synthesis of the best available evidence and not distorted by single studies. Prioritization of farm-level adaptations to climate change will also need to account for the different crops grown within a target region, local farmer attitudes to risk and the time horizons over which investments are made (Lobell *et al.*, 2008).

6.6 Evaluating and Prioritizing Adaptation Measures

The semi-arid tropical environments in South Asia and West Africa have varied agroclimatic conditions in terms of soils and climate, which along with socio-economic conditions of the farmers determine the prevailing production systems and their capacity to meet their food and livelihood security. Although temperature is projected to increase in all the production environments of South Asia and West Africa, the direction and magnitude of changes in rainfall will vary from region to region. Thus, in future, the impact of climate change on the productivity of production systems will vary from region to region and would require different adaptation strategies to cope with climate change. The strategies at the farm level would include different agronomic, land and water management and genetic improvement measures for the smallholder farmers to adopt. Before these measures are successfully adopted by the farmers, they must be evaluated for their potential contribution to enhance yields and farmers' income. In this section, we have given examples of evaluating various agronomic and genetic improvement technologies in terms of their contribution to enhance crop yields under both current and future climates of the selected sites in South Asia and West Africa, just to highlight that a number of technologies must be evaluated and prioritized before they are recommended for adoption at any site.

Singh *et al.* (2014b) used the CROPGRO–Groundnut model to assess the potential of various agronomic technologies for adapting groundnut to climate change by 2050 at two sites in Andhra Pradesh (Anantapur and Mahboobnagar) and one site in Gujarat (Junagadh), where groundnut is predominantly grown by farmers in India. They first evaluated the effect of sowing date on the productivity of groundnut (Table 6.4) and later evaluated its combined effect with other agronomic management practices at the three sites (Table 6.5). At Anantapur the maximum increase in yield was simulated with supplemental irrigation, followed by a delay in sowing and growing a longer maturity variety. At Mahboobnagar, the maximum yield gain was with delayed sowing, followed by growing a longer maturity variety, supplemental irrigation and application of crop residues. At Junagadh, the yield increase was the maximum with normal sowing date, followed by supplemental irrigation and application of crop residues. Thus the relative contribution and prioritization of agronomic practices to increase groundnut yield under climate change varied with the target region.

Singh *et al*. (2014b,c,d) evaluated the potential benefits of genetic improvement technologies (crop maturity duration, enhanced yield potential, drought- and heat-tolerance traits and their combinations) for adapting sorghum, groundnut and chickpea to the current and future climates of the target sites in South Asia and Africa where these crops are predominantly grown. Crop system models and a virtual cultivars approach were used to evaluate the genetic traits for the sites. For rainy season sorghum the selected sites were Akola and Indore in India and Samanko and Cinzana in Mali (Singh *et al*., 2014b). The commonly grown sorghum cultivars used in the simulation were CSV 15 at both Akola and Indore, CSM 335 at Samanko and CSM 63E at Cinzana. Decreasing crop life-cycle duration of each cultivar by 10% decreased yields at the respective sites under both current and future climates (Table 6.6). In contrast, increasing crop life-cycle duration by 10% increased yields up to 10% at Akola, 9% at Indore, 7% at Samanko and 31% at Cinzana under climate change. Enhancing yield potential traits (radiation use efficiency, relative leaf size and partitioning of assimilates to the panicle each increased by 10%) in the longer cycle cultivars increased the yields by 11–26% at Akola, 18–23% at Indore, 10–11% at Samanko and 14–36% at Cinzana across virtual cultivars under current climates of the sites. The relative benefits due to yield potential traits were even larger under climate change. Except for the Samanko site, yield gains were larger by incorporating drought tolerance than heat tolerance under the current climate (Table 6.6). Under future climates of the sites the yield gains were higher, however, by incorporating heat tolerance at Akola, Samanko and Cinzana but not at Indore. Net benefits of incorporating both drought and heat tolerance increased yield up to 17% at Akola, 9% at Indore, 7% at Samanko and 15% at Cinzana under climate change.

Table 6.4. Impact of three sowing conditions on pod yield (kg ha^{-1}) of groundnut at the three sites.

	Anantapur		Mahboobnagar		Junagadh	
Sowing condition	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)
Normal sowing under baseline climate	1230	–	2250	–	2230	–
Normal sowing under climate change	1180	–4	2500	11	2480	11
Delayed sowing under climate change	1440	18	2610	16	2380	7
Least significant difference ($p = 0.05$)	151		115		153	

Source: Singh *et al*., 2014a

Table 6.5. Pod yield of groundnut under climate change with best sowing date (see Table 6.4) plus other agronomic management practices at Anantapur, Mahboobnagar and Junagadh.

	Anantapur		Mahboobnagar		Junagadh	
	Yield (kg ha^{-1})	Change (%)	Yield (kg ha^{-1})	Change (%)	Yield (kg ha^{-1})	Change (%)
Best sowing date (BSD)	1440	–	2610	–	2480	–
BSD + Crop residue	1510	4	2800	7	2580	4
BSD + In-situ water conservation	1530	6	2670	2	2550	3
BSD + Short-duration variety	1290	–11	2250	–14	2480	0
BSD + Long-duration variety	1570	9	2850	9	2420	–2
BSD + Supplemental irrigation	1920	33	2820	8	2630	6
Least significant difference ($p = 0.05$)	99	–	89	–	92	–

Source: Singh *et al.*, 2014a

Table 6.6. Yield of baseline sorghum cultivars under current climate and under climate change by 2050 and percentage gain or loss in yield by incorporating short duration, long duration, yield potential, drought tolerance and heat tolerance traits in virtual cultivars at the selected sites in India and West Africa.

Site	Yield (kg ha^{-1})	Short duration	Long duration	Yield potential	Drought tolerance	Heat tolerance	Drought + heat tolerance
Baseline climate							
Akola	3790	–16	4	11–26	3–6	1–4	5–8
Indore	3540	–15	4	18–23	4–10	0	4–10
Samanko	2700	–8	4	10–11	1	2	1–2
Cinzana	2210	–26	20	14–36	5–6	1–3	6–9
Climate change 2050							
Akola	3127	–20	10	16–30	3–4	8–12	13–17
Indore	3329	–22	9	19–30	2–8	0	4–9
Samanko	2389	–21	7	11–23	0	5–7	6–7
Cinzana	1540	–38	31	21–48	4–6	5–9	9–15

Source: Singh *et al.*, 2014b

For chickpea, the selected sites were Hisar, Indore and Nandhyal in India, Zaloke in Myanmar, DebreZeit in Ethiopia, Kabete in Kenya and Ukiriguru in Tanzania (Singh *et al.*, 2014c). Under both baseline climate and climate change, the 10% shorter duration cultivars gave higher yield than the longer duration cultivars across sites, except for Nandhyal and Zaloke (Table 6.7). Drought tolerance is a priority trait for increasing yields at Indore and Zaloke, whereas at Nandhyal both heat tolerance and yield potential are the priority traits under climate change. At Zaloke and DebreZeit, heat tolerance is not a priority trait under climate change as compared to drought tolerance or yield potential traits. At Ukiriguru adjusting the crop life cycle will be sufficient to increase the yield of chickpea, whereas at Kabete the use of baseline cultivar with some degree of drought tolerance will be required for higher yields. At Hisar, a short-duration cultivar along with some degree of drought and heat tolerance and yield potential traits will be needed to increase yields under climate change.

For groundnut the selected sites were Anantapur and Jungadh in India, Samanko

Table 6.7. Yield of baseline chickpea cultivars under current climate and under climate change by 2050 and percentage gain or loss in yield by incorporating short duration, long duration, yield potential, drought tolerance and heat tolerance traits in virtual cultivars at the selected sites in South Asia and East Africa.

Site	Yield (kg ha^{-1})	Short duration	Long duration	Yield potential	Drought tolerance	Heat tolerance	Drought + heat tolerance
Baseline climate							
Hisar	1322	0	–27	6–12	4–16	8–9	14–16
Indore	1813	4	–13	1–6	19–22	3	19–27
Nandhyal	1181	–7	2	4–7	12–16	0	8–10
Zaloke	960	0	6	5	18–21	0	17–20
DebreZeit	1341	11	–18	0	4–15	0	4–15
Kabete	2031	–6	–14	6	10–19	0	11–18
Ukiriguru	1608	1	–18	0	3–13	0	2–11
Climate change 2050							
Hisar	1547	10	–41	8	10–14	3–6	11–20
Indore	2115	5	–15	3–6	14–20	5	15–29
Nandhyal	994	–11	0	4–11	8–11	2–13	15–31
Zaloke	1134	0	7	3–4	13–19	0	13–18
DebreZeit	1674	13	–21	5	8–14	0	9–15
Kabete	2398	–3	–13	0	11–16	0	12–15
Ukiriguru	1503	18	–26	0	5–7	3–4	4–9

Source: Singh *et al.*, 2014c

in Mali and Sadore in Niger (Singh *et al.*, 2014d). In the case of groundnut, increasing crop maturity by 10% increased yields up to 15% at Anantapur, 23% at Samanko and 7% at Sadore, and sustained the yields at Junagadh under the baseline climate; however, under climate change the yield benefits were somewhat less (Table 6.8). Increasing yield potential of the crop by increasing leaf photosynthesis rate, partitioning to pods and seed-filling duration each by 10% increased pod yield by 9 to 13% under baseline climate and 11 to 14% under climate change relative to the baseline yields across the four sites. Under the current climates of Anantapur, Junagadh and Sadore, the yield gains were larger by incorporating drought tolerance than heat tolerance; however, under climate change the relative contribution of heat tolerance increased for the three sites. Under climate change, the yield gains from incorporating both drought and heat tolerance increased up to 13% at Anantapur, 12% at Junagadh and 31% at Sadore (Table 6.8). At the Samanko site, the yield gains from drought or heat tolerance were negligible. It was concluded from the above studies that priority traits of crops varied with the target sites and climate scenarios and different combinations of plant traits will be needed to increase and sustain crop productivity in current and future climates of the sites. The model findings of these studies need to be field tested, however, before adoption by plant breeders or farmers.

Tao and Zhang (2010) applied a super-ensemble-based probabilistic projection system (SuperEPPS) to project maize productivity during the 2050s in the North China Plain to examine the relative contributions of adaptation options. On the basis of a large number of simulation outputs from the super-ensemble-based projection, the results showed that, without adaptation, maize yield could decrease on average by 13.2–19.1% during the 2050s, relative to 1961–1990. In comparison with the experiment without adaptation, using high-temperature sensitive varieties, maize yield could on average increase by 1.0–6.0%, 9.9–15.2% and 4.1–5.6%, by adopting adaptation options of early planting, fixing variety

Table 6.8. Yield of baseline groundnut cultivars under current climate and under climate change by 2050 and percentage gain or loss in yield by incorporating short duration, long duration, yield potential, drought tolerance and heat tolerance traits in virtual cultivars at the selected sites in India and West Africa.

Site	Yield (kg ha^{-1})	Short duration	Long duration	Yield potential	Drought tolerance	Heat tolerance	Drought + heat tolerance
Baseline climate							
Anantapur	1228	–17	15	11	3–5	1–3	5–7
Junagarh	2229	–1	0	9	6–7	1–2	7–8
Samanko	1286	–24	23	11–13	1–2	2	1–2
Sadore	759	–12	7	11	13–15	2–3	15–21
Climate change 2050							
Anantapur	1171	–14	13	11–12	4–5	5–9	10–13
Junagarh	2477	0	–2	11	5–7	3–6	9–12
Samanko	1799	–21	19	11–12	0	1	1–2
Sadore	792	–9	1	13–14	16–17	9–12	25–31

Source: Singh *et al*., 2014d

growing duration and late planting, respectively. In contrast, using high-temperature-tolerant varieties, maize yield could on average increase by –2.4% to –1.4%, 34.7–45.6%, and 5.7–6.1%, respectively. They concluded that the biggest benefits would result from the development of new crop varieties that are high-temperature tolerant and have high thermal requirements to reach maturity. They also showed that, depending on the climate and variety, the spatial patterns of relative contributions of adaptation options can be geographically quite different.

Rosegrant *et al*. (2014) assessed the future scenarios of the potential impact and benefits of alternative agricultural technologies in terms of future yield and production growth, food security, demand and trade. To achieve these goals, they used the Decision Support System for Agrotechnology Transfer (DSSAT) crop model to simulate changes in yields for rice, maize and wheat following the adoption of different technologies, agricultural practices, improved varieties or a combination of these, compared to a business-as-usual baseline. Across the three crops, the largest yield gains, in percentage terms, are in Africa, South Asia, and parts of Latin America and the Caribbean. Their analysis found wide heterogeneity in yield response, making it important to target specific technologies to specific regions and countries. Heat-tolerant varieties, no-till, nitrogen-use efficiency and precision agriculture are technologies with particularly great potential for yield improvement in large parts of the world. Moving these technologies forward will require institutional, policy and investment advances in many areas.

Among the three crops studied, maize is the most important crop in sub-Saharan Africa (SSA). The DSSAT results indicated that no-till was the most yield-increasing technology (30% yield boost for maize) for this region because of its soil-protection and water-enhancing properties under both climate change scenarios (Rosegrant *et al*., 2014). Although maize is largely rainfed in the region at this point, irrigation development is growing rapidly, and both maize and rice will increasingly benefit from irrigation. Improved nitrogen use efficiency (NUE) in maize and rice also showed the largest benefits for SSA with a more than 10% yield improvement by 2050 under rainfed conditions for both crops and up to 96% improvement for irrigated maize and a 50% yield increase for irrigated rice by 2050 under the CSIRO A1B climate change scenario. These positive results again underline the strong demand for enhanced nutrient availability, nitrogen in particular, for cereal crops in the region. Integrated soil fertility management (ISFM) also showed large yield-enhancing benefits for maize in SSA compared to the baseline scenario, with yields growing 21% under rainfed and 16% under irrigated conditions. High ISFM impacts are probably due to the low levels of nutrients available in African soils, generally considered the key yield constraints in this region. Moreover, drought tolerance showed major benefits in low rainfall environments of East Africa under the CSIRO A1B scenario (17% yield improvement) and still resulted in 7% improvement under the MIROC A1B scenario. Also, in higher-rainfall environments (rainfall greater than 500 mm per season), drought-tolerant crops do best in West and East Africa under both climate change scenarios. Crop protection for rainfed maize would have the largest ex-ante yield impacts for SSA, with yield improvements in the range of 12–20%, depending on the cropping system and climate change scenario. For disease and insect control, only South Asia has similarly high yield benefits. Among the combined technologies assessed, SSA showed high beneficial yield impacts of combined no-till and heat-tolerant varieties, with ex-ante yield increases of more than 40% for rainfed and more than 100% for irrigated conditions under both climate change scenarios.

Similar to SSA, yield gains in South Asia were particularly high for no-till for both wheat and maize; for ISFM for rice and wheat; for precision agriculture for wheat; drought tolerance for wheat across all rainfall regimes; and NUE across all three cereals (Rosegrant *et al*., 2014). South Asia also displayed substantial benefits from advanced irrigation technologies for wheat, most likely due to the severe water shortages that the region already faces and that will be compounded as a result of climate change. Heat tolerance is another technology with high potential in South Asia, particularly for maize and wheat. Irrigated maize yields were 66% higher with heat tolerance, and irrigated wheat yields were 33% higher under the MIROC climate change scenario. Yield improvements were lower but still substantial under the CSIRO climate change scenario. Crop protection also resulted in higher yields *ex ante*, with largest benefits for maize through weed and insect control. In contrast, impacts for disease were roughly equally distributed across the three cereals, with yield improvements ranging from 1 to 33%. Given that South Asia's wheat yields are under particular threat of adverse climate change effects, a range of technologies can make major inroads into reducing these adverse effects for this key staple and breadbasket region.

The above-described examples show that the potential of agrotechnologies to increase crop yields varies from region to region under both current and future climates. These technologies must be evaluated and prioritized in terms of productivity enhancements, social and economic benefits to the rural population at large before they are promoted for achieving food security under conditions of climate change in future.

6.7 Summary and Conclusion

Increasing the concentration of greenhouse gases in the atmosphere is warming the globe. In West Africa the median annual temperature increase will be about 3.3°C by the end of the 21st century with much less certainty about changes in rainfall in the region. In South Asia, model projections show a median increase of 3.3°C in annual mean temperature by the end of the 21st century. Most models project a decrease in precipitation in December, January and February (DJF) and an increase during the rest of the year. The median change is 11% by the end of the 21st century, and seasonally is –5% in DJF and 11% in JJA (June, July and August), with a large inter-model spread.

There are both direct and indirect effects of climate change on crop production. Direct effects include change in mean climate (higher temperatures, changing precipitation patterns) and increased climate variability and extremes. Indirect effects of climate change are a change in water availability, change in length of growing season, climate-induced high runoff and soil erosion and a changed scenario of pests and diseases. The non-climate impacts related to GHG emissions are CO_2 fertilization and effects of ozone on vegetation. Despite the potential positive effects on crop yields, elevated CO_2 may, however, be detrimental to yield quality of certain crops. Ozone is a major secondary air-pollutant, which at current concentrations has been shown to have significant negative impacts on both crop yield and yield quality. Until now, most studies have focused more on the direct effects of changes in mean climate state on crops and did not consider changes in extremes or in indirect effects of climate change.

Using a meta-analysis of different independent published studies, Knox *et al*. (2012) estimated that mean yield change for all crops is –8% by the 2050s with strong variations among crops and regions. Across Africa, mean yield changes of –17% for wheat, –5% for maize, –15% for sorghum and –10% for millet and across South Asia of –16% for maize and –11% for sorghum were estimated. Such robust evidence of future yield change in Africa and South Asia can be surprising in regards to the diverging projections of summer monsoon rainfall in a warmer climate. Rainfall is the primary driver for rainfed crop productivity in the region, especially in West Africa where some studies make projections of wetter conditions and some predict more frequent droughts. This is because the potential wetter conditions or elevated CO_2 concentrations hardly counteract the adverse effect of higher temperatures.

In spite of the threat of crop yield losses in a warmer climate, developing countries in the tropics have the potential to more than offset such adverse impacts by implementing more intensive agricultural practices and adapting agriculture to climate and environmental change. Crop-level adaptation measures include agronomic, land and water management and genetic improvement measures to enhance and sustain crop yields under climate change conditions. Some autonomous adaptations, such as shifting planting dates, modifying crop rotations or the uptake of pre-existing crop varieties, will help offset some negative impacts of climate change. However, the greatest benefits in food-insecure regions are likely to arise from more expensive policy driven adaptation measures that include the development of new crop varieties and uptake of new technologies such as the expansion of irrigation infrastructure. These will require substantial investments by farmers, governments and development agencies.

The impact of proposed technological adaptations should be examined in both current and future climates of the target regions. In this way the management changes that are beneficial in a range of environments can be separated from the management changes that are specifically targeted at climate change. The potential of adaptation technologies in terms of yield response will certainly vary from region to region under both current and future climates. These technologies must be evaluated and prioritized for the target regions in terms of productivity enhancements and social and economic benefits to the rural populations at large before they are promoted for achieving food security under conditions of climate change in future.

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References

Aggarwal, P.K. (2008) Impact of climate change on Indian agriculture: impacts, adaptation and mitigation. *Indian Journal of Agricultural Sciences* 78, 911–919.

Ainsworth, E.A. and Long, S.P. (2005) What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytologist* 165, 351–371.

Ainsworth, E.A. and McGrath, J.M. (2010) Direct effects of rising atmospheric carbon dioxide and ozone on crop yields. In: Lobell, D. and Burke, M. (eds) *Climate Change and Food Security: adapting agriculture to a warmer world*. Springer, pp. 109–130.

Arnell, N.W., Cannell, M.G.R., Hulme, M., Kovats, R.S., Mitchell, J.F.B., *et al*. (2002) The consequences of CO_2 stabilisation for the impacts of climate change. *Climatic Change* 53, 413–446.

Ashrit, R.G., Douville, H. and Rupa Kumar, K. (2003) Response of the Indian monsoon and ENSO-monsoon teleconnection to enhanced greenhouse effect in the CNRM coupled model. *Journal of the Meteorological Society of Japan Weather Collection Magazine* 81, 779–803.

Baethgen, W.E. (2010) Climate risk management for adaptation to climate variability and change. *Crop Science* 50, 70–76.

Beddington, J. (2010) Food security: contributions from science to a new and greener revolution. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365, 61–71.

Berg, A., de Noblet-Ducoudré, N., Sultan, B., Lengaigne, M. and Guimberteau, M. (2012) Projections of climate change impacts on potential C4 crop productivity over tropical regions. *Agricultural and Forest Meteorology* 170, 89–102.

Burke, E.J., Brown, S.J. and Christidis, N. (2006) Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *Journal of Hydrometeorology* 7, 1113–1125.

Butt, T., McCarl, B., Angerer, J., Dyke, P. and Stuth, J. (2005) The economic and food security implications of climate change in Mali. *Climatic Change* 68, 355–378.

Centritto, M. (2005) Photosynthetic limitations and carbon partitioning in cherry in response to water deficit and elevated [CO2]. *Agriculture, Ecosystems & Environment* 106, 233–242.

Challinor, A., Wheeler, T., Garforth, C., Crauford, P. and Kassam, A. (2007) Assessing the vulnerability of food crop systems in Africa to climate change. *Climatic Change* 83, 381–399.

Challinor, A., Osborne, T.M., Morse, A., Shaffrey, L.C., Wheeler, T.R., Weller, H. and Vidale, P.L. (2009) Methods and resources for climate impacts research: achieving synergy. *Bulletin of the American Meteorological Society* 90, 836–848.

Cheke, R.A. and Tratalos, J.A. (2007) Migration, patchiness, and population processes illustrated by two migrant pests. *Bioscience* 57, 145–154.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., *et al*. (2007) Regional climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., *et al*. (eds) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK, pp. 847–940.

Collomb, P. (1999) A narrow road to food security from now to 2050. *FAO Economica*. Paris, FAO.

Cooper, P., Rao, K.P.C., Singh, P., Dimes, J., Traore, P.S., *et al*. (2009) Farming with current and future climate risk: advancing a “Hypothesis of Hope” for rainfed agriculture in semi-arid tropics. *Journal of SAT Agricultural Research* 7, 1–9.

Craufurd, P.Q. and Wheeler, T.R. (2009) Climate change and the flowering time of annual crops. *Journal of Experimental Botany* 60, 529–539.

Deressa, T., Hassan, R., Ringler, C., Alemu, T. and Yesuf, M. (2009) Determinants of farmers’ choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change* 19, 248–255.

Deryng, D., Sacks, W.J., Barford, C.C. and Ramankutty, N. (2011) Simulating the effects of climate and agricultural management practices on global crop yield. *Global Biogeochemical Cycles* 25, GB 2006. DOI: 10.1029/2009GB003765.

Dilling, L. and Lemos, M.C. (2011) Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change* 21, 680–689.

Döll, P. (2002) Impact of climate change and variability on irrigation requirements: a global perspective. *Climatic Change* 54, 269–293.

Douville, H., Royer, J.-F., Stephenson, D.B., Tyteca, S., Polcher, J., *et al*. (2000) Impact of CO_2 doubling on the Asian summer monsoon: robust versus model dependent responses. *Journal of Meteorological Society of Japan* 78, 1–19.

Druyan, L.M. (2011) Studies of 21st-century precipitation trends over West Africa. *International Journal of Climatology* 31, 1415–1424.

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., *et al*. (2007) Food, fibre and forest products. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 273–313.

Ebi, K.L., Padgham, J., Doumbia, M., Kergna, A., Smith, J., *et al*. (2011) Smallholders adaptation to climate change in Mali. *Climatic Change* 108, 423–436.

Evans, N., Baierl, A., Semenov, M.A., Gladders, P. and Fitt, B.D.L. (2008) Range and severity of a plant disease increased by global warming. *Journal of Royal Society Interface* 5, 525–531.

FAO (2010) Crop Statistics for Africa and S. Asia. http://faostat.fao.org (Accessed 7 July 2015).

Field, C., Jackson, R. and Mooney, H. (1995) Stomatal responses to increased CO_2: implications from the plant to the global scale. *Plant, Cell & Environment* 18, 1214–1255.

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., *et al*. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365, 2973–2989.

Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanan, M.S. and Xavier, P.K. (2006) Increasing trend of extreme rain events over India in a warming environment. *Science* 314, 1442–1445.

Gregory, P.J., Johnson, S.N., Newton, A.C. and Ingram, J.S.I. (2009) Integrating pests and pathogens into the climate change/food security debate. *Journal of Experimental Botany* 60, 2827–2838.

Hedhly, A., Hormaza, J.I. and Herrero, M. (2008) Global warming and sexual plant reproduction. *Trends in Plant Science* 14, 30–36.

Howden, S., Crimp, S. and Nelson, R. (2010) Australian agriculture in a climate of change. In: Jubb, I., Holper, P. and Cai, W. (eds) *Proceedings of Managing Climate Change: Papers from the GREENHOUSE 2009 Conference*, CSIRO, Melbourne.

Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M. and Meinke, H. (2007) Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America* 104, 19691–19696.

IAASTD (2009) Agriculture at crossroads. *International Assessment of Agricultural Knowledge, Science and Technology for Development – Synthesis Report*, pp. 106.

IPCC (2007) *Climate Change 2007: the Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

IPCC (2013) Summary for policymakers. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., *et al*. (eds) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York.

Kesava Rao, A.V.R., Wani, S.P., Singh, K.K., Ahmad, M.I., Srinivas, K., *et al*. (2013) Increased arid and semi-arid areas in India with associated shifts during 1971–2004. *Journal of Agrometeorology* 15, 11–18.

Kettlewell, P.S., Sothern, R.B. and Koukkari, W.L. (1999) UK wheat quality and economic value are dependent on the North Atlantic oscillation. *Journal of Cereal Science* 29, 205–209.

Knox, J., Hess, T., Daccache, A. and Wheeler, T. (2012) Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters* 7, 1–8.

Kumar, K.K., Deshpande, N.R,. Mishra, P.K., Kamala, K. and Rupa Kumar, K. (2003) Future scenarios of extreme rainfall and temperature over India. In: *Proceedings of the Workshop on Scenarios and Future Emissions, Indian Institute of Management (IIM), Ahmedabad, 22 July 2003*. NATCOM Project Management Cell, Ministry of Environment and Forests, Government of India, New Delhi, pp. 56–68.

Kumar, K.K., Kumar, K.R., Ashrit, R.G., Deshpande, N.R. and Hansen, J.W. (2004) Climate impacts on Indian agriculture. *International Journal of Climatology* 24, 1375–1393.

Lal, M. and Harasawa, H. (2001) Future climate change scenarios for Asia as inferred from selected coupled atmosphere-ocean global climate models. *Journal of the Meteorological Society of Japan* 79, 219–227.

Lal, M., Nozawa, T., Emori, S., Harasawa, H., Takahashi, K., *et al*. (2001) Future climate change: implications for Indian summer monsoon and its variability. *Current Science* 81, 1196–1207.

Laux, P., Jacket, G., Tingem, R. and Kunstmann, H. (2010) Impact of climate change on agricultural productivity under rainfed conditions in Cameroon – a method to improve attainable crop yields by planting date adaptations. *Agricultural and Forest Meteorology* 150, 1258–1271.

Li, Y.P., Ye, W., Wang, M. and Yan, X.D. (2009) Climate change and drought: a risk assessment of crop-yield impacts. *Climate Research* 39, 31–46.

Licker, R., Johnston, M., Foley, J.A., Barford, C., Kucharik, C.J., *et al*. (2010) Mind the gap: how do climate and agricultural management explain the 'yield gap' of croplands around the world? *Global Ecology and Biogeography* 19, 769–782.

Lioubimtseva, E. and Henebry, G.M. (2009) Climate and environmental change in arid Central Asia: impacts, vulnerability and adaptations. *Journal of Arid Environments* 73, 963–977.

Lobell, D.B. and Field, C.B. (2007) Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters* 2, 1–7.

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

Long, S.P., Ainsworth, E.A., Rogers, A. and Ort, D.R. (2004) Rising atmospheric carbon dioxide:

plants face the future. *Annual Review of Plant Biology* 55, 591–628.

Lotze-Campen, H. (2011) Climate change, population growth, and crop production: an overview. In: Yadav, S.S., Redden, R.J., Hatfield, J.L., Lotze-Campen, H. and Hall, A.E. (eds) *Crop Adaptation to Climate Change*. Wiley-Blackwell, Chichester, UK, pp. 1–11.

Luo, Q., Bellotti, W., Williams, M. and Wang, E. (2009) Adaptation to climate change of wheat growing in South Australia: analysis of management and breeding strategies. *Agriculture, Ecosystems and Environment* 129, 261–267.

Mary, A. and Majule, A. (2009) Impacts of climate change, variability and adaptation strategies on agriculture in semi-arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania. *African Journal of Environmental Science and Technology* 3, 206–218.

Memmott, J., Craze, P.G., Waser, N.M. and Price, M.V. (2007) Global warming and the disruption of plant-pollinator interactions. *Ecology Letters* 10, 710–717.

Mercer, K., Martinez-Vasquez, A. and Perales, H. (2008) Asymmetrical local adaptation of maize landraces along an altitudinal gradient. *Evolutionary Applications* 1, 489–500.

Mertz, O., Mbow, C., Reenberg, A. and Diouf, A. (2009) Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environmental Management* 43, 804–816.

Mills, G., Hayes, F., Wilkinson, S. and Davies, W.J. (2009) Chronic exposure to increasing background ozone impairs stomatal functioning in grassland species. *Global Change Biology* 15, 1522–1533.

Mutekwa, V. (2009) Climate change impacts and adaptation in the agricultural sector: the case of smallholder farmers in Zimbabwe. *Journal of Sustainable Development in Africa* 11, 237–256.

Nearing, M.A., Pruski, F.F. and O'Neal, M.R. (2004) Expected climate change impacts on soil erosion rates: a review. *Journal of Soil and Water Conservation* 59, 43–50.

Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., *et al*. (2009) *Climate Change Impact on Agriculture and Costs of Adaptation.* International Food Policy Research Institute, Washington, DC.

Newman, J.A. (2004) Climate change and cereal aphids: the relative effects of increasing CO_2 and temperature on aphid population dynamics. *Global Change Biology* 10, 5–15.

Niklaus, P.A. (2007) Climate change effects on biogeochemical cycles, nutrient, and water supply. In: Newton, P., Carran, R.A., Edwards, G.R and Niklaus, P.A. (eds) *Agroecosystems in a Changing Climate.* Taylor & Francis, Boca Raton, Florida, pp 11–52.

Parry, M.L., Rosenzweig, C., Iglesias, A., Livermore, M. and Fischer, G. (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* 14, 53–67.

Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., *et al*. (2010) The impacts of climate change on water resources and agriculture in China. *Nature* 467, 43–51.

Pittock, A.B. and Jones, R.N. (2000) Adaptation to what and why? *Environmental Monitoring and Assessment* 61, 9–35.

Porter, J.R. and Gawith, M. (1999) Temperatures and the growth and development of wheat: a review. *European Journal of Agronomy* 10, 23–36.

Reddy, B.V.S., Ashok Kumar, A., Reddy, P.S., Ibrahim, M., Ramaiah, B. *et al*. (2010) Cultivar options for salinity tolerance in sorghum. *Journal of SAT Agricultural Research* 8, 1–4.

Reilly, J., Tubiello, F., McCarl, B., Abler, D., Darwin, R., *et al*. (2003) US agriculture and climate change: new results. *Climatic Change* 57, 43–69.

Rosegrant, M.W., Koo, J., Cenacchi, N., Ringler, C., Robertson, R., *et al*. (2014) *Food Security in a World of Natural Resource Scarcity: The Role of Agricultural Technologies.* International Food Policy Research Institute, Washington, DC.

Roudier, P., Sultan, B., Quirion, P. and Berg, A. (2011) The impact of future climate change on West African crop yields: what does the recent literature say? *Global Environmental Change* 21, 1073–1083.

Rupa Kumar, K. and Ashrit, R.G. (2001) Regional aspects of global climate change simulations: Validation and assessment of climate response over Indian monsoon region to transient increase of greenhouse gases and sulfate aerosols. *Mausam* 52, 229–244.

Rupa Kumar, K., Sahai, A.K., Krishna Kumar, K., Patwardhan, S.K., Mishra, P.K., *et al*. (2006) High-resolution climate change scenarios for India for the 21st century. *Current Science* 90, 334–345.

Schlenker, W. and Lobell, D.B. (2010) Robust negative impacts of climate change on African agriculture. *Environmental Research Letters* 5, 014010.

Seo, S. (2010) Is an integrated farm more resilient against climate change? A micro-econometric analysis of portfolio diversification in African agriculture. *Food Policy* 35, 32–40.

Sinclair, T.R., Pinter Jr, P.J., Kimball, B.A., Adamsen, F.J., LaMorte, R.L., *et al.* (2000) Leaf nitrogen concentration of wheat subjected to elevated (CO_2) and either water or N deficits. *Agriculture, Ecosystems & Environment* 79, 53–60.

Singh, P., Nedumaran, S., Boote, K.J., Gaur, P.M., Srinivas, K. and Bantilan, M.C.S. (2014a) Climate change impacts and potential benefits of drought and heat tolerance in chickpea in South Asia and East Africa. *European Journal of Agronomy* 52, 123–137.

Singh, P., Nedumaran, S., Ntare, B.R., Boote, K.J., Singh, N.P., *et al.* (2014b) Potential benefits of drought and heat tolerance in groundnut for adaptation to climate change in India and West Africa. *Mitigation and Adaptation Strategies for Global Change* 19, 509–529.

Singh, P., Nedumaran, S., Traore, P.C.S., Boote, K.J., Rattunde, H.F.W., *et al.* (2014c) Quantifying potential benefits of drought and heat tolerance in rainy season sorghum for adapting to climate change, *Agricultural and Forest Meteorology* 185, 37–48.

Singh, P., Singh, N.P., Boote, K.J., Nedumaran, S., Srinivas, K. and Bantilan, M.C.S. (2014d) Management options to increase groundnut productivity under climate change at selected sites in India. *Journal of Agrometeorology* 16, 52–59.

Sivakumar, M.V.K., Das, H.P. and Brunini, O. (2005) Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. *Climatic Change* 70, 31–72.

Staley, J.T. and Johnson, S.N. (2008) Climate change impacts on root herbivores. In: Johnson, S.N. and Murray, P.J. (eds) *Root Feeders: an ecosystem perspective*. CAB International, Wallingford, UK.

Sultan, B. (2012) Global warming threatens agricultural productivity in Africa and South Asia. *Environmental Research Letters* 7, 041001.

Tao, F. and Zhang, Z. (2010) Adaptation of maize production to climate change in North China plain: quantify the relative contributions of adaptation options. *European Journal of Agronomy* 33, 103–116.

Tao, F. and Zhang, Z. (2011) Impacts of climate change as a function of global mean temperature: maize productivity and water use in China. *Climatic Change* 105, 409–432.

Thomas, R.J. (2008) Opportunities to reduce the vulnerability of dry land farmers in Central and West Asia and North Africa to climate change. *Agriculture, Ecosystems & Environment* 126, 36–45.

Thornton, P.K., Jones, P.G., Alagarswamy, G., Andresen, J. and Herrero, M. (2010) Adapting to climate change: agricultural system and household impacts in East Africa. *Agricultural Systems* 103, 72–82.

Tingem, M. and Rivington, M. (2009) Adaptation for crop agriculture to climate change in Cameroon: turning on the heat. *Mitigation and Adaptation Strategies for Global Change* 14, 153–168.

Travasso, M., Magrin, G., Rodríguez, G., Solman, S. and Núñez, M. (2009) Climate change impacts on regional maize yields and possible adaptation measures in Argentina. *International Journal of Global Warming* 1, 201–213.

Tubiello, F. and Fischer, G. (2006) Reducing climate change impacts on agriculture: global and regional effects of mitigation, 2000–2080. *Technological Forecasting and Social Change* 74, 1030–1056.

Tubiello, F. N., Rosenzweig, C., Goldberg, R. A., Jagtap, S. and Jones, J.W. (2002) Effects of climate change on US crop production: simulation results using two different GCM scenarios. Part I: wheat, potato, maize, and citrus. *Climate Research* 20, 259–270.

Unnikrishnan, A.S., Kumar, K.R., Fernandes, S.E., Michael, G.S. and Patwardhan, S.K. (2006) Sea level changes along the Indian coast: Observations and projections. *Current Science* 90, 362–368.

Van de Geisen, N., Liebe, J. and Jung, G. (2010) Adapting to climate change in the Volta Basin, West Africa. *Current Science* 98, 1033–1037.

Van Dingenen, R., Dentener, F.J., Raes, F., Krol, M.C., Emberson, L. and Cofala, J. (2009) The global impact of ozone on agricultural crop yields under current and future air quality legislation. *Atmospheric Environ*ment 43, 604–618.

Vara Prasad, P.V., Boote, K.J., Allen, L.H. and Thomas, J.M.G. (2003) Super-optimal temperatures are detrimental to peanut (*Arachis hypogaea* L.) reproductive processes and yield at both ambient and elevated carbon dioxide. *Global Change Biology* 9, 1775–1787.

Verchot, L.V., Noordwijk, M.V., Kandji, S., Tomich, T., Ong, C., *et al.* (2007) Climate change: linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change* 12, 901–918.

Watson, R., Zinyowera, M. and Moss, R. (1996) Climate change 1995 – impacts, adaptation and mitigation of climate change. *Contribution of working Group II to the Second Assessment Report of the IPPC.* Cambridge University Press, Cambridge.

Webster, P.J. (2008) Myanmar's deadly daffodil. *Nature Geoscience* 1, 488–490.

Wheeler, T.R., Craufurd, P.Q., Ellis, R.H., Porter, J.R. and Prasad, P.V.V. (2000) Temperature variability and the yield of annual crops. *Agriculture, Ecosystems and Environment* 82, 159–167.

Wullschleger, S.D., Tschaplinski, T.J. and Norby, R.J. (2002) Plant water relations at elevated CO_2 – implications for water-limited environments. *Plant, Cell & Environment* 25, 319–331.

Zhou, X.L., Harrington, R., Woiwod, I.P., Perry, J.N., Bale, J.S. and Clark, S.J. (1995) Effects of temperature on aphid phenology. *Global Change Biology* 1, 303–313.

Ziska, L.H. and Runion, G.B. (2007) Future weed, pest and disease problems for plants. In: Newton, P., Carran, R.A., Edwards, G.R. and Niklaus, P.A. (eds) *Agroecosystems in a Changing Climate.* Taylor and Francis, Boca Raton, Florida, pp. 261–287.

Ziska, L.H., Bunce, J.A., Shimono, H., Gealy, D.R., Baker, J.T., *et al*. (2012) Food security and climate change: on the potential to adapt global crop production by active selection to rising atmospheric carbon dioxide. *Proceedings of the Royal Society Biological Sciences* 279, 4097–4105.

7 Scoping Climate Change Adaptation Strategies for Smallholder Farmers in East Africa – A Multi-dimensional, Multi-scenario Impact Assessment

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Abstract

This chapter assesses the characteristics of current and future agricultural systems, land use, agricultural output, output price, cost of production, and farm and household size in response to climate change. This analysis also compared both current and projected future climate (2030), with and without adaptation, and for different socio-economic scenarios (Representative Agricultural Pathways, RAPs) in two study areas in Kenya. A new approach to impact assessment, the Tradeoff Analysis Model for Multi-Dimensional Impact Assessment (TOA-MD) was adopted for this analysis, which simulated technology adoption and associated economic, environmental and social outcomes in a heterogeneous farm population for a regional impact assessment. These case studies yield new insights into the way that adaptation strategies could improve the livelihoods of smallholder farmers operating in the mixed crop–livestock systems in East Africa.

7.1 Introduction

The changing climate is exacerbating existing vulnerabilities of the poorest people who depend on semi-subsistence agriculture for their survival. Sub-Saharan Africa (SSA) in particular is predicted to experience considerable negative impacts of climate change. The latest IPCC Report (2014) emphasizes that adaptation strategies are essential and these must be developed and promoted within the broader economic development policy context. Addressing adaptation in the context of small-scale, semi-subsistence agriculture in SSA raises special challenges that cannot be addressed adequately by the approaches taken thus far in most studies. Most of the existing research has focused on impacts of climate change and adaptation in the commercial agricultures of

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industrialized countries. In the relatively few studies conducted in SSA, agricultural research has either focused on individual crops, has used aggregated data and models, or used statistical analysis too general to be useful for site-specific adaptation strategies. One of the important constraints to carrying out this type of research is that the data demands are high, because site-specific biophysical and socio-economic data are required, typically obtained from costly multi-year farm-level surveys. The development and application of relatively simple and reliable methods for *ex-ante* evaluation of adaptation strategies at the household and system levels are needed to provide timely assessments of the projected impacts of climate change and feasible possibilities for adaptation. In this chapter we describe and apply a regional integrated assessment methodology that is currently being developed and used in the Agricultural Model Intercomparison and Improvement Project (http://www.agmip.org, Rosenzweig *et al*., 2013). The methodology uses survey, experimental and modelled data to *ex ante* assess impacts of climate change and adaptation on heterogeneous farm populations for a range of climate and socio-economic scenarios (Claessens *et al*., 2012). We show results for two study areas with smallholder farming systems in Kenya.

7.2 Methods

7.2.1 TOA-MD as a climate impact and adaptation assessment tool

For the integrated assessment of climate change impact, adaptation strategies and poverty we use the Tradeoff Analysis model for Multi-Dimensional Impact Assessment (TOA-MD, Antle, 2011; Antle *et al*., 2014). The TOA-MD model is a parsimonious, generic model for analysis of technology adoption and impact assessment in a population of heterogeneous farms. The approach integrates socio-economic and biophysical survey data on farmers' land allocation, outputs and cost of production and characterizes the spatial heterogeneity in economic returns to baseline and alternative systems. Baseline systems are parameterized on the basis of detailed household surveys of farm populations. The alternative systems (climate change with and without adaptation) are parameterized based on a combination of simulation modelling (crop, livestock and climate), experimental data and socio-economic scenarios (Representative Agricultural Pathways, RAPs, see below).

7.2.2 Survey data

For the two study areas we used household surveys that were collected in different projects and we extracted household information from the databases for which complete data (quantities and prices) on inputs (such as seeds, labour, fertilizer and manure), outputs (crop yields, milk production and land areas), farm management and off-farm income were available. The data are then used to calculate statistics needed to implement the TOA-MD model for the different farm activities (crops and milk production) for the baseline system in each study area (Table 7.1). It is possible to stratify the farm population to look at differential impacts on sub-populations.

7.2.3 Climate change projections, impact assessment and adaptation

For future climate change projections, we used data from the IPCC Fourth Assessment Report (2007), a combination of several global circulation models (GCMs), emission scenarios and different spatial and temporal downscaling techniques (Table 7.1). Downscaled future climate data were used as input to crop and livestock simulation models, where available, to simulate the impacts of climate change on future production. Activities for which no simulation models are available were parameterized on the basis of experimental data from the literature and/or expert knowledge. Feasible adaptation strategies to be tested were in most cases solicited from stakeholder consultations and

Table 7.1. Information about the study areas, agricultural systems and models used for the analysis.

Study area	General info	No. of households surveyed	Activities	Climate projections	Simulation models	Adaptation strategies tested
Machakos-Makueni, Kenya	13,500 km^2, 400–2100 masl, bimodal rainfall 500–1300 mm yr^{-1}, mean annual temp 15–25°C, population 1,980,000 (2009), avg household 7.8 persons, avg farm size 3.3 ha.	120 (Gachimbi *et al.*, 2005)	Maize–bean, Napier, mixed, sweet potato, milk	2030, HadCM3 (Mitchell *et al.*, 1998), ECHam4 (Roeckner *et al.*, 1996) GCMs, and SRES A1FI and B1. Downscaling as in Thornton *et al.* (2010)	DSSAT (Jones *et al.*, 2003) for maize and beans. Literature for others (Claessens *et al.*, 2012)	Imz: improved maize, dpsp: dual-purpose sweet potato, dpsplw: low-yielding dpsp, dpsp1: dpsp with 100% of base milk yield under climate change (CC), dpsp12: dpsp with 120% of base milk yield under CC
Vihiga, Kenya	563 km^2, 1300–1500 masl, bimodal rainfall 1800–2000 mm yr^{-1}, mean annual temp 14–32°C, population 550,000 (2009), avg household 4.7 persons, avg farm size 0.5 ha.	119 (Waithaka *et al.*, 2005)	Maize, mixed, beans, vegetables, napier, milk	2030, HadCM3 (Mitchell *et al.*, 1998), ECHam4 (Roeckner *et al.*, 1996) GCMs, and SRES A1FI and B1. Downscaling as in Thornton *et al.* (2010)	DSSAT (Jones *et al.*, 2003) for maize and beans. Literature for others (Claessens *et al.*, 2012)	Imz: improved maize, dpsp: dual-purpose sweet potato, dpsplw: low-yielding dpsp, dpsp1: dpsp with 100% of base milk yield under climate change (CC), dpsp12: dpsp with 120% of base milk yield under CC

parameterized on the basis of simulation models, literature and expert knowledge.

7.2.4 Socio-economic scenarios: Representative Agricultural Pathways (RAPs)

Most agricultural climate impact assessments have evaluated the impacts of climate change on current or adapted systems within historical or present socio-economic conditions. To be consistent with the assumptions that were used to generate climate change projections it would be desirable to evaluate potential climate change impacts under plausible future socio-economic scenarios. The global climate modelling and impact assessment communities are developing two new concepts, Representative Concentration Pathways or RCPs and Shared Socio-economic Pathways or SSPs (Arnell *et al*., 2011). The concept of Representative Agricultural Pathways (RAPs) has been proposed as a way to extend these scenario concepts to be more relevant to agricultural models (Antle *et al*., 2014). RAPs include global economic conditions, such as rates of growth in aggregate agricultural productivity, as well as region-specific agricultural and economic development conditions. In this study, in addition to current conditions we propose two RAPs that are broadly consistent with the types of SSPs that are currently under development. The proposed RAPs for Kenya correspond to future worlds characterized by different degrees of adaptation challenges. In RAP_L (low adaptation challenges) Kenya follows a more positive economic development trajectory with higher rates of economic growth, movement of labour out of agriculture into other sectors, reductions in rural household size and increases in farm size. Investments in infrastructure and more open trade policies lead to higher real prices for traded agricultural commodities such as maize and lower prices for agricultural inputs. In RAP_H (high adaptation challenges) Kenya continues to experience a low rate of economic growth, rural populations and household sizes increase while farm sizes decline.

Fig. 7.1. Location of the study areas in Kenya.

Infrastructure deteriorates, trade policy discourages exports so that prices to farmers remain at current levels, but policy imposes high taxes on imports of critical inputs. The qualitative RAPs were translated into quantitative scenarios by making assumptions about compound annual rates of change from the baseline values from 2012 to 2030 for prices, costs of production and farm size (Claessens *et al*., 2012).

7.2.5 Study areas

The location of the study areas is shown in Fig. 7.1. Some general information about the geography and agricultural systems in the study areas can be found in Table 7.1.

7.3 Results and Discussion

First the TOA-MD model was used to carry out a sensitivity analysis to different assumptions about the effects of climate change and adaptation on productivity, holding constant other scenario components such as prices and costs of production. The aggregated economic impact of climate change and simulated adaptation strategies on farmers is shown in Fig. 7.2. The interpretation of the curves representing the farm population is as follows: the point where a curve crosses the x-axis shows the percentage of farms that gain from the scenario. Accordingly, the points on a curve to the left of where it crosses the x-axis show the percentage of farms with gains (i.e. negative losses) greater than the amount shown on the y-axis. Conversely, points to the right of where a curve crosses the x-axis show the percentage of farms with losses less than or equal to the amount on the y-axis. Figure 7.2 shows that climate change is projected to have a negative economic impact on 76% of the farmers in Vihiga and on 62% in Machakos. By testing different adaptation strategies with the TOA-MD model, we can simulate aggregate economic impacts on the farm population in each of the study areas. Figure 7.2 shows that, in the aggregate, the different adaptation strategies simulated have a higher impact on the farm population in Vihiga than in Machakos. The 'best' adaptation strategy (dpsp12) can bring back the percentage of farmers losing out from climate change from 76% to 37% in Vihiga, but only from 62% to 50% in Machakos. We also analysed the effects of climate change and the different adaptation strategies on poverty rates with the TOA-MD model. Both disaggregated and aggregated impacts of climate change and the simulated adaptation strategies are shown in Table 7.2. The base poverty rate in Machakos is higher than in Vihiga (73% versus 62%). Climate change increases the poverty rate to 78% in Machakos and to 69% in Vihiga. The introduction of an improved maize variety as an adaptation strategy has a profound effect in Machakos, offsetting the negative effects of climate change at the aggregate level (poverty rates are back to the base level of 73%). In Vihiga this introduction of improved maize brings back the poverty rates from 69% to 65%. Substituting half of the mixed system with low-yielding dual-purpose sweet potato (dpsplw) hardly reduces the percentage of farmers that are negatively affected by climate change in Vihiga but reduces this from 62% to 57% in Machakos (Fig. 7.2). This strategy has a similar effect to the improved maize option in Machakos. Increasing the average yield of dpsp to the observed levels but keeping the loss in milk yield at 20% (dpsp) has a positive effect in both study areas. On aggregate, Vihiga is still negatively impacted by climate change but non-dairy farmers are already gaining from this strategy (the poverty rate is back to the base level). By increasing milk yields to 100% and 120% of the base level, Machakos has limited additional gains, whereas in Vihiga the percentage of negatively affected farmers goes down to 50% and 37%, respectively. In general, this analysis indicates that introduction of an improved maize variety or a low-yielding dpsp in the cropping system of Machakos would be sufficient to offset the negative impacts of climate change. For Vihiga, however, average-yielding dpsp together with improved feed and/or livestock breeds that can produce 100% of the base milk yield under climate change are needed to fully offset the impacts of climate change. The disaggregated results in Table 7.2 show that

Table 7.2. Impacts of climate change and simulated adaptation strategies on poverty rates in Vihiga and Machakos. From Claessens *et al.* (2012).

	Vihiga			Machakos			
	Poverty rate (% of farm population living on <$1 per day)						
Scenario	No dairy	Dairy	Total	No dairy	Dairy	Irrigated	Total
Base	85	38	62	85	43	54	73
CC	89	49	69	89	51	57	78
imz	87	42	65	85	44	50	73
dpsplw	88	42	66	85	44	50	73
dpsp	85	41	63	83	43	50	71
dpsp1	85	36	60	83	41	49	71
dpsp12	85	30	58	83	38	48	70

Table 7.3. Impacts of climate change and RAPs on poverty rates in Machakos and Vihiga, Kenya (per cent changes from base period values).

	Vihiga		Machakos	
	Changes in poverty rate (% of farm population living on <$1 per day)			
Scenario	No Dairy	Dairy	No Dairy	Dairy
CC	4.7	28.9	4.7	18.6
RAP_L	–23.5	–55	–15.3	–30.2
RAP_L+CC	–16.5	–52	–9.4	–23.3
RAP_H	4.7	26.3	7.1	16.2
RAP_H+CC	7.1	31.6	9.4	23.3

From: Claessens *et al.* (2012). CC = climate change impacts, base socio-economic conditions; RAP_L = favourable socio-economic pathway (low adaptation challenges); RAP_L + CC = favourable socio-economic pathway with climate change; RAP_H = unfavourable socio-economic pathway (high adaptation challenges); RAP_H + CC = unfavourable socio-economic pathway with climate change.

farmers with dairy in Vihiga benefit relatively more from increases in milk yield than dairy farmers in Machakos. Vihiga has a larger percentage of dairy farmers in the population (62% versus 15% in Machakos) and higher base milk yields and net returns.

Second, the TOA-MD model was used to implement socio-economic scenarios based on the RAPs described above by translating these narratives into specific parameterizations of the model that included prices, costs of production and socio-economic characteristics of farms. Table 7.3 shows the percentage changes in poverty rates simulated for climate change impacts without adaptation under current socio-economic conditions, for farms with crops only and farms with dairy, for the two RAPs. An important finding is that the effects of different plausible socio-economic pathways may be more important than the effects of climate change, even in climate-vulnerable regions such as these. Poverty rates increase by 5–29% under base socio-economic conditions and climate change, and increase even more under the adverse socio-economic scenario (RAP_H). However, under the positive RAP_L, poverty rates are projected to decline by 15–55%; climate change would offset those gains some, but poverty rates would nevertheless be from 9 to 52% lower with climate change under this positive development scenario.

7.4 Summary and Conclusion

The development and application of relatively simple and reliable methods for assessing the impacts of climate change and adaptation strategies at the farm population level are needed to provide timely recommendations on the potential impacts of alternative technologies and policies. The TOA-MD model was presented as a method to evaluate the impacts of climate change and the economic viability of adaptation strategies using the kinds of data that are typically available in countries where semi-subsistence agricultural systems are prominent. The method was applied to the mixed crop–livestock systems of the Vihiga and Machakos study areas in Kenya. With a combination of simulated and estimated changes in crop and livestock productivity, the economic impacts of climate change to 2030 were analysed. Climate change is projected to have a negative economic impact on 76% of the farmers in Vihiga and on 62% in Machakos. Different adaptation strategies were tested by changing crop and livestock productivity under climate change and by introducing socio-economic scenarios based on Representative Agricultural Pathways (RAPs). The analysis suggests that introducing an improved maize variety or low yielding dpsp in the cropping system of Machakos may be sufficient to offset the negative

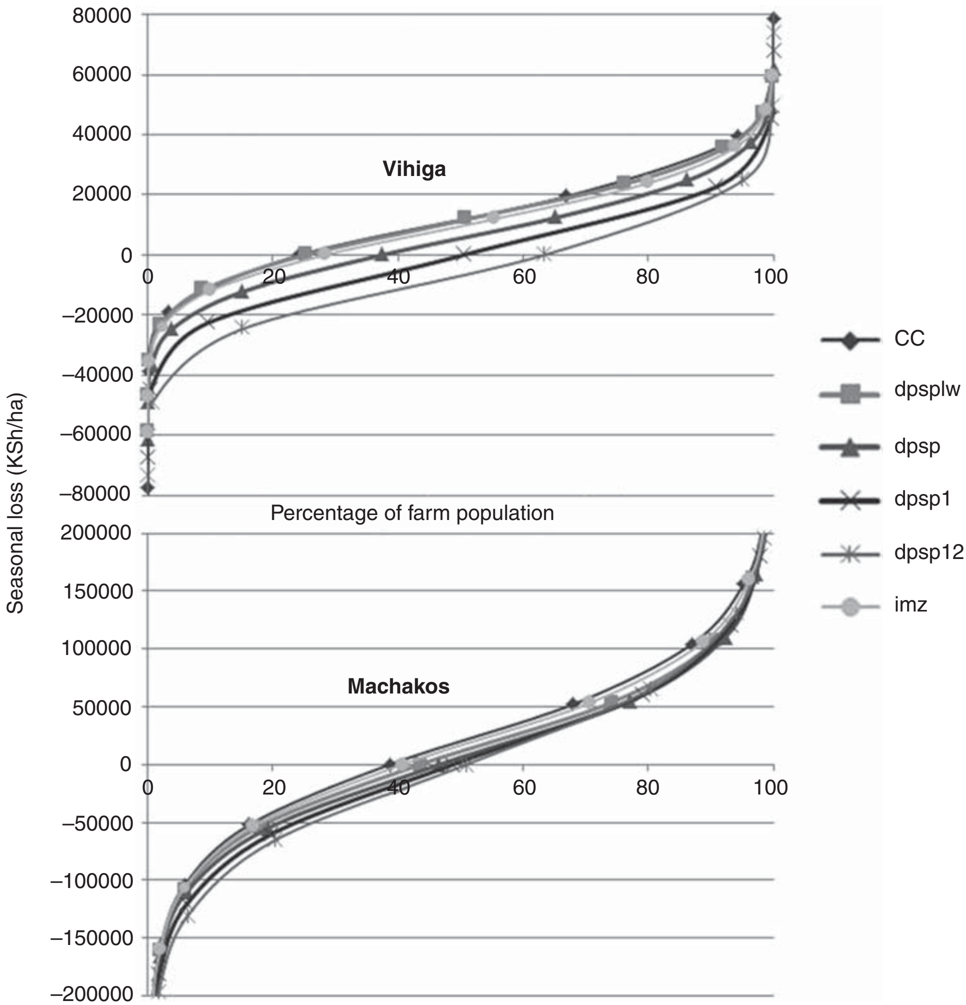

Fig. 7.2. Aggregated economic impact of climate change and simulated adaptation strategies on farmers in Vihiga and Machakos-Makueni, Kenya. Notation of legend as in Table 7.1. KSh = Kenyan Shilling. From Claessens *et al.* (2012).

effects of climate change, whereas improved feed and livestock breeds are necessary for adaptation to climate change in Vihiga. As in all scenario studies using models, and especially in the context of climate change, various assumptions and uncertainties are associated with using the proposed approach and results should be interpreted with caution. Despite these limitations, the methodology presented in this study shows the potential to yield new insights into the way realistic adaptation strategies could improve the livelihoods of smallholder farmers operating in the mixed crop–livestock systems in East Africa and other parts of the world. TOA-MD offers a flexible, generic framework that can use available and modelled data to evaluate climate impact and adaptation strategies under a range of socio-economic scenarios.

References

Antle, J.M. (2011) Parsimonious multi-dimensional impact assessment. *American Journal of Agricultural Economics* 93, 1292–1311.

Antle, J.M., Stoorvogel, J. and Valdivia, R. (2014) New parsimonious simulation methods and tools to assess future food and environmental security of farm populations. *Philosophical Transactions of the Royal Society B: Biological Sciences* 369, 20120280.

Arnell, N., Kram, T., Carter, T., Ebi, K., Edmonds, J., *et al*. (2011) A framework for a new generation of socioeconomic scenarios for climate change impact, adaptation, vulnerability, and mitigation research. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Barros, V., Field, C.B., *et al*. (eds) *Workshop Report of the Intergovernmental Panel on Climate Change Workshop on Socio-Economic Scenarios*. IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam, Germany.

Claessens, L., Antle, J., Stoorvogel, J., Valdivia, R., Thornton, P. and Herrero, M. (2012) A method for evaluating climate change adaptation strategies for small-scale farmers using survey, experimental and modeled data. *Agricultural Systems* 111, 85–95.

Gachimbi, L.N., van Keulen, H., Thuranira, E.G., Karuku, A.M., de Jager, A., *et al*. (2005) Nutrient balances at farm level in Machakos (Kenya), using a participatory nutrient monitoring (NUTMON) approach. *Land Use Policy* 22, 13–22.

IPCC (Intergovernmental Panel on Climate Change) (2007) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.

IPCC (2014) *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Cambridge University Press, Cambridge, UK and New York.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., *et al*. (2003) The DSSAT cropping system model. *European Journal of Agronomy* 18, 235–265.

Mitchell, J.F.B., Johns, T.C. and Senior, C.A. (1998) Transient response to increasing greenhouse gases using models with and without flux adjustment. *Hadley Centre Technical Note 2*. UK Met Office, Bracknell, UK.

Roeckner, E., Oberhuber, J.M., Bacher, A., Christoph, M. and Kirchner, I. (1996) ENSO variability and atmospheric response in a global coupled atmosphere-ocean GCM. *Climate Dynamics* 12, 737–754.

Rosenzweig, C., Jones, J.W., Hatfield, J.L., Ruane, A.C., Boote, K.J., *et al*. (2013) The agricultural model intercomparison and improvement project (AgMIP): protocols and pilot studies. *Agricultural and Forest Meteorology* 170, 166–182.

Thornton, P.K., Jones, P.G., Alagarswamy, G., Andresen, J. and Herrero, M. (2010) Adapting to climate change: agricultural system and household impacts in East Africa. *Agricultural Systems* 103, 73–82.

Waithaka, M.M., Thornton, P.K., Herrero, M., Shepherd, K.D., Stoorvogel, J.J., *et al*. (2005) System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high-potential areas of Eastern Africa. *Final Program Report to the Ecoregional Fund to Support Methodological Initiatives*. ILRI, Nairobi, Kenya.

8 Sustainable Land and Water Management Approaches in Sub-Saharan Africa: Farm-level Analysis of Climate Change Mitigation and Adaptation from Sub-Saharan Africa

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Abstract

Climate change is increasingly recognized as a worldwide phenomenon that impacts people's livelihoods in many ways. This is especially important in rural areas where households are heavily dependent on rainfed agriculture and natural resources in general for their livelihoods. Farmers' perception and the household level data were collected and analysed to understand the determinants of adaptation to climate change and the impacts of sustainable land and water management practices on agricultural productivity and climate change vulnerability. Rainfall has been showing a decreasing trend and increased variability so there have been new practices adopted by farmers to minimize the impact. Using the case study of Niger, this chapter explores the question of what drives adaptation to climate change in the region, including the adoption of land and water management practices using econometric analysis. Context-specific policy recommendations were drawn from the results that enhance the adaptation to climate change and reduce vulnerability through integrated land, water and soil management practices.

8.1 Introduction

Climatic changes are affecting the livelihoods of many people in various ways and more significantly farmers who largely rely on rainfed agriculture and other natural resources to earn their livings. The West African Sudano-Sahelian region is particularly negatively affected by climate change. Global Circulation Models (GCMs) are predicting higher temperatures and more variable rainfall and higher frequency of

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drought, floods, sandstorms, windstorms and other extreme weather events (NAPA, 2006; Boko *et al*., 2007). Niger's economy has been affected significantly by frequent droughts and floods (Table 8.1). These extreme events have significantly affected land-based sectors, resulting in low or negative economic growth. This is due to the high dependency of the country on agriculture, which contributes 38% of the gross domestic product (GDP). Irrigation in the country is poorly developed, accounting for only 27% of the irrigable area (Svendsen *et al*., 2009), despite the large share of land area under the Sahara desert (77%) and drylands (23%), which require irrigation for reliable agricultural production. Such poorly developed irrigation does not cushion significantly the frequent droughts that the country faces.

Niger has also been facing land degradation, which has increased vulnerability of the already fragile Sahelian ecosystem. Between 1990 and 2007, Niger lost an average of 43,000 ha of forest. Not all of the forest loss is due to deforestation. Drought also contributes to loss of forests. Drought episodes between 1968 and 2001 led to a loss of 338,180 ha of forest (Table 8.1), a loss equivalent to 27% of the forested area in 2007 (1.241 million hectares) (FAOSTAT, 2007). Croplands have also been affected by severe soil nutrient depletion and declining fallow periods (Abdoulaye and Sanders, 2005). Niger is among the countries with the most severe soil nutrient depletion, losing 56 kg/ha of nitrogen, phosphorus and potassium in the 2002–2004 period (Henao and Baanante, 2006). Wind and water soil erosion also contribute to 26–46 tonnes/ha loss of soil, which is above the rate of soil formation (Chappell, 1996). The Nigerian government and its development partners are fully aware of the impacts of the droughts, climate change and land degradation. One of the ministries deals specifically with control of desertification (Ministere de l'Environnement et de la Lutte Contre la Désertification), a focus that underlines the seriousness of the country in addressing desertification. Tree planting and natural regeneration programmes have also led to increased vegetation in some areas of Niger. The government has also designed several policies and strategies to address climate change and climatic shocks such as droughts. One of such strategies is the National Adaptation Programme of Action (NAPA), which the government prepared in 2006 as part of the United Nations Framework Convention on Climate Change (UNFCCC). The government also formulated the rural development strategy in 2003, the strategy of which is to reduce rural poverty through sustainable agriculture and livestock programmes and non-farm income (Jauffret, 2009). Despite these efforts and successes, investment in land-based sectors remains low. Expenditure of Niger on agricultural research and development (R&D) as share of the agricultural GDP was 0.28% of its 2005 agricultural GDP (AgGDP) on research and development (Beintema and Stads, 2011).

8.2 Government Policies and Strategies for Adaptation to Climate Change and Land Degradation

Responding to its arid climate, limited vegetation and water resources, and severe land degradation, Niger designed the NAPA in

Table 8.1. Drought events and their impact on land-based sectors.

Year	Impact on land-based sectors	Source
1998	588 ha of rice, 203 ha of orchard lost	Report on assessment of environmental events, 2005
1968–1973, 1977–1985	More than 50% of livestock lost	National report on vulnerability, 2003
1968, 1973, 1977, 1985, 2001	338,180 ha of forest lost	CNEDD (2005)

2006, which identified 14 adaptation action strategies with the broad objective of ensuring food security, sustainable resource management and poverty reduction. The strategic activities are: (i) pasture and rangeland improvement; (ii) increasing livestock productivity by improving livestock local breeds; (iii) development and protection of water resources for domestic use, irrigation and livestock; (iv) promotion of sustainable land and water management (SLWM) practices that enhance adaptation to climate change; (v) promoting peri-urban agriculture and non-farm activities; (vi) capacity building of organizational skills of rural community development groups; (vii) control of climate-related pests and diseases; and (viii) dissemination of climate information. As is the case in other countries, however, the total budget set for NAPA is small and its implementation is short term (2–3 years). Investment into the NAPA has also been largely funded by donors, with limited contribution by the government. This reveals the weak political will of the government to put the NAPA into a sustainable and long-term operation required to enhance its effectiveness. Hence, the effectiveness of NAPA has been limited, even though it has spurred country-level policy awareness of climate change and the need to design policies and strategies to enhance adaptation and mitigation.

As mentioned earlier, protection and planting of trees is one of the success stories in Niger that have attracted global attention. As part of the implementation of the National Action Plan (NAP), the government started promoting sustainable pasture management, water harvesting, tree planting, developing livestock markets and other strategies. A large area of degraded land has been rehabilitated through the presidential programme on land rehabilitation and several donor-funded projects. According to Adam *et al*. (2006), at least 250,000 hectares of land have been rehabilitated using tree planting and soil and water conservation measures, whereas more than 3 million hectares have been reforested through farmer-managed natural regeneration since the mid-1980s (Reij *et al*., 2009).

Other sustainable land management (SLM) projects have been operating in Niger since the 1980s. More than 50 projects and programmes have promoted SLM in Niger (World Bank, 2009). These programmes have shown significant impacts. For example, remote sensing images have suggested contrasting patterns of land-use change on either side of the Niger–Nigeria border over the past few decades, with a 're-greening' apparent to a greater extent in southern Niger than in northern Nigeria, particularly after accounting for the effects of changes in rainfall. The area of unexplained re-greening in Niger is centred in the area of the Projet Intégré Keita (PIK).

Policies and institutional reforms have also contributed to re-greening of the Sudano-Sahelian zone in Niger. For example, Mortimore *et al*. (2001) found increasing tree density on farmers' fields in Maradi owing to a widespread practice of farmer protection of valuable natural on-farm trees, a practice that was not done to a significant extent in the past. The change in the farmer practice could be explained by two factors:

1. Institutional changes that gave more ownership and local authority for management of natural resources. The government has embarked on strategies to promote vegetative technologies, which are supported by policy changes to replace the unwritten 'right of axe' by giving ownership rights to those who plant trees (Abdoulaye and Abasse, 2005). Likewise, the 2004 forestry law also grants ownership rights to those who plant woodlots or protect forest resources on their private land. The government also decentralized management of natural resources through the 2003 Rural Development Strategy (RDS). RDS gives the local governments the responsibility to manage natural resources.

2. The positive influence of the institutional changes in the 1970's and 1980's on farmers. Policy induced increases in the value of trees and other natural resources prompted the farmers to safeguard and own them.

This study was conducted to answer the following questions: (i) What types, modalities and conditions of SLWM investments are the most relevant for adaptation to current variability and future climate change? (ii) What context-specific actions can improve the contribution of SLWM investments to adaptation and mitigation, considering improved information, institutions, and policy, programme and regulatory instruments? (iii) What are the best synergies between water and land resource management to generate mitigation and adaptation benefits? The study aims to generate practical, context-specific recommendations of SLWM approaches and practices that improve food security and economic prospects, while reducing climate-related risks and greenhouse gas emissions. This report covers data collected from focus group discussions, resource mapping and household surveys.

8.3 The Tahoua Region

8.3.1 Characterization of the Tahoua region

The Tahoua region is located in the centre of the Niger, covers 106,677 km^2, and had a population of about 2.5 million inhabitants in 2008. Nearly 70% of the population lives in the southern and central zones of the region. Population density is highest in the valleys of Badaguichiri, Keïta, Tarka and Majiya, all located in the south-east. Haoussas, Tuaregs, Peuls and Arabs are the major ethnic groups. Rainfall decreases from the south to the north, with a low annual average of 350 mm for the region as a whole (period 1981–1990). The north of Tahoua, and the districts of Tchinta and Asalak are located north of the isohyet 350 mm. The average rainfall is more than 450 mm to the south of Konni district. The region can be subdivided into two zones: a pastoral zone in the north and an agricultural zone in the south. In the southern zone, millets–cowpea dominates the production systems. In the entire region, onion is the main cash and export crop.

8.3.2 Sustainable land and water management projects

More than 10 sustainable land management projects have been or are being implemented in the region of Tahoua (Table 8.2). These projects are mainly promoting soil and water conservation options such as stone bunds, forest and agricultural half-moons ('demi-lunes'), zaï, small dikes, trenches, small dams, etc., the construction of small dams and water catchments, live fences, wind breaks, biological fixation of 'Kori', vegetative bands, etc., and agroforestry technologies (tree plantations, improved land clearing, and assisted natural regeneration, etc.).

Table 8.2. Executed and ongoing projects in the Tahoua region.

Project title	Period	Source of funding
Projet Intégré Keita (PIK)	1984–2002	FAO/ Italie
PDR. ADM	1984–2000	Italie-PAM
Projet Energie II	1989–1998	
Projet de Développement rural de Tahoua (PDRT)	1991–1995	RFA
PGRN (Projet de gestion des ressources naturelles)	1996–2001	IDA/NORVE/PB
Projet Tahoua Vert	1994–1998	PAYS-BAS
PGRNTT	1988–1992	DDA/SUISSE
PRIVAT	1991–2001	PAYS-BAS
Projet de Mobilisation des Eaux de Tahoua	2001– ?	FAD/PAM
Programme d'Actions Communautaires (PAC)	2004–2007	
Projet Spécial du Président de la République du Niger		
Projet de Gestion Intégrée des Ecosystèmes (PGIE)		

8.3.3 Data and analytical methods

Eight villages were selected in the Tahoua region (Niger). Analysis of historical data of the sites showed that changes in climate in these sites were comparable. Using the data from the Niger GIS Bureau on all villages in the Tahoua region, selection of villages was restricted to those located at less than 15 km from the closest weather station.[1] A total of 51 villages were identified which were further categorized into four categories based on the inputs and discussions with key resource persons from the Ministry of Environment and Fight Against Desertification. The four categories are:

1. Villages with high market access and SLWM projects.
2. Villages with high market access but no SLWM projects.
3. Villages with low market access and a SLWM project
4. Villages with low market access and no SLWM project (Table 8.3).

Focus group discussions (FGD) were conducted to understand and access the perceptions of the community on the bio-physical and socio-economic changes, the timeline of their occurrence and the adaptation strategies they had been following in response to these changes. Information gathered from FGD was also used to design the questionnaire for the household survey. Household-level data were collected and analysed to understand the determinants of adaptation to climate change and the impacts of SLWM practices on agricultural productivity. Table 8.4 reports the number of households and communities who participated in the study in each site. Qualitative analysis of drivers and responses, including technological and institutional responses, as well as the impact of the responses were done using focus group discussion and based on inputs from key informants. The focus group discussions were held with members of the general public, but with an emphasis on agriculturalists in all communities selected. About 12–15 community members were invited to participate in each group discussion. Participants were selected based on their age, gender, primary activity and knowledge of the community and other major changes. To ensure that women are well-represented in the discussion, an equal mix of gender was required. A guideline was used to discuss the following major topics: timeline of major recent events, livelihoods and changes; resource management practices and changes; reasons for changes and perceptions of drivers; responses to drivers; institutional responses and impacts of responses.

A household and plot survey instrument was designed to capture data on household capital endowment, shocks experienced by the household, and climate change perceptions and responses, land holdings, tenure and management, plot production, inputs and outputs, livestock assets and production, access to rural services and expenditure on food and non-farm income. A total of 245 households from the eight communities were interviewed (Table 8.4). The qualitative information and data collected from the focus group discussions were compiled

Table 8.3. Villages visited in the Tahoua region in Niger.

Village	Commune	Department	SLWM project present?	Market access
Tcherassa Goune	Birni Nkonni	Birni Nkonni	Yes	Yes
Guidan Bahago	Doguerawa	Birni Nkonni	No	No
Toudoun Adaraoua	Doguerawa	Birni Nkonni	Yes	No
Kenouar Nomade	Doguerawa	Birni Nkonni	No	No
Seyte	Ibohamane	Keita	Yes	No
Inguira	Ibohamane	Keita	Yes	No
Dogon Gona	Bouza	Bouza	Yes	Yes
Elroudou	Sabon Gari	Madaoua	No	No

Table 8.4. Selected sites and household sample in each agroecological zone.

	Number of households/ communities
Household	245
Communities	8
High market, SLWM	2
High market, no SLWM	2
Low market, SLWM	2
Low market, no SLWM	2

and summarized in tabular and graphical format to capture commonality and divergence of responses across different sites.

In order to understand the drivers of response to climate change and draw implications on the vulnerability, we use household level data to estimate the determinants of response to climate change. The empirical model used is:

$$Pr(R=1)=f(sc_i,\, hc_i,\, pc_i,\, rs_i,\, mf_i,\, lt_i,\, pl_i,\, e) \tag{8.1}$$

Where $Pr(R)$ is probability to respond to climate change, sc_i is social capital i, hc_i is human capital i, pc_i is physical capital i, rs_i is rural service i, mf_i is meso level factors, lt_i is land tenure i, pl_i is plot level factor i, e is random error iid ~ N(0,1).

Of interest is to understand the drivers of adoption of SLWM practices because such understanding will help identify factors that could be used to enhance adaptation to climate change. Using plot level data, we estimate the determinants of adoption of SLWM practices using the following model:

$$Pr(Y_i=1)=f(sc_i, hc_i, pc_i, rs_i, mf_i, lt_i, pl_i, e) \tag{8.2}$$

Where $Pr(Y_i)$ is the probability to adopt land management practice i, and all other notations are as defined in Eqn 8.1.

We also use plot level data to estimate the impacts of SLWM practices on crop productivity and production risks. For accessing the risk associated with production, the methodology of Just and Pope (1979) has been followed. The hypothesis tested is that the SLWM practices will help to reduce the variance of production among those who have adopted the practices. In order to estimate the effect of a particular SLWM practice on risk, we divide the sample into those with and those without the SLWM practice. The mean productivity for the subsample is calculated and then for each plot observation a deviation about the mean or variance measure can be calculated. Following Just and Pope (1979):

$$g(x,v)=f(x)+\sqrt{h(x)}e(v) \tag{8.3}$$

where f(x) is mean production function, i.e. E(Y)=f(x), h(x) is a variance of Y, h(x) > 0 and e(v) ~ N(0,h(x)). x is a vector of the following covariates c_i, hc_i, pc_i, rs_i, mf_i, lt_i, pl_i, which are defined in Eqn 8.1.

If $\frac{\partial var(y)}{\partial x}=\frac{\partial h}{\partial x}>0, 1$, land management i is risk increasing. If $\frac{\partial h}{\partial x}<0, 1$, land management i is risk reducing.

Plot productivity is measured as the net value per unit area (subtracting out purchased inputs). Value is used since many plots have more than one commodity (e.g. maize and beans) so there needs to be some basis for aggregation.

8.4 Results

8.4.1 Climate change and variability

We assess climate change using rainfall data obtained from stations around the case study sites. Although these data may not reflect the actual rainfall where the case study villages are located, the trends are expected to be very similar. Depending on data availability, the data also cover different time periods. Rainfall trends are available from 1936 to 2000 from Madoua station in the Sahel zone, which covers only 1% of Niger's surface area. This area receives an average of 600–800 mm of rainfall. The decadal mean annual rainfall showed a steep decline between 1936–1945 and 1976–1985 during which period there was a prolonged drought in Niger in 1968–1973 and 1977–1985, which caused significant crop failure and livestock decimation. For example, more than 50% of livestock died during the 1977–1985 drought. Rainfall has been increasing since but has not yet reached the 1936–1945 level. The rainfall variability – represented by standard deviation – has shown an upward trend but the change is not significant. The Illela rainfall station, which is also in Sahel zone, shows a downward trend with an increasing variability.

Overall, rainfall in the Tahoua region shows a declining trend with increasing variability. This is consistent with the community perception and with the GCM predictions. The decadal average precipitation shows a 15 mm decrease per 10 years in the Illela station in the southern part of the region and by 15 mm in Madoua station in the middle part of the region. This is, respectively, about 1.5 mm and 1.0 mm decline per year. At the same time, rainfall variability has been increasing by 5.4 mm and 3.4 mm per decade in Illela and Madoua stations respectively (Figs 8.1 and 8.2).

8.4.2 Response to climate change

Communities were asked during FGD to discuss how they have responded to climate change. Households were also asked the same question. In all communities, responses differed significantly – largely depending on their major livelihoods. We first summarize the responses given by communities during the FGD. We then discuss the responses at household level. We give detailed discussion on SLWM practices used to respond to climate change and less details on non-SLWM responses because our focus is on SLWM. It should be noted, however, that the SLWM practices were adopted for multiple objectives and not as a response to climate change alone.

Livestock and rangeland management

All eight villages reported to have developed livestock corridors and five of the eight villages reported to have adopted controlled grazing as part of their response to climate change and overgrazing (Fig. 8.3). These investments were done to reduce conflicts resulting from reduced grazing area owing to climate change and expansion of cropland into woodlands, grasslands and other land uses used for grazing. Pastoralists have been moving southward, encroaching on cropped areas, as a consequence of which conflicts have been erupting. The communities opined that they had opted the practice of

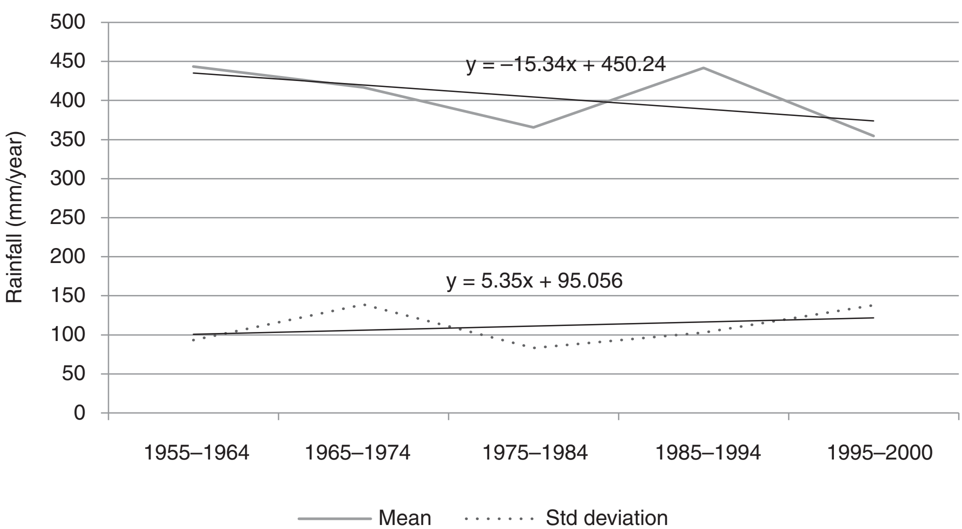

Fig. 8.1. Mean annual rainfall and variability, Illela, Republic of Niger.

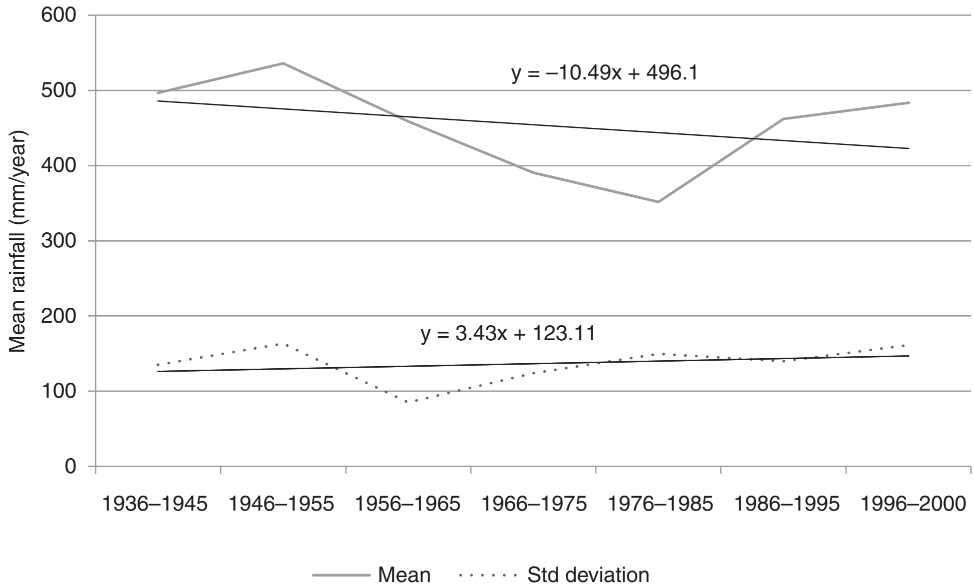

Fig. 8.2. Decadal mean annual rainfall, Madoua station (Sahel zone, Tahoua region), Niger.

controlled grazing which is on similar lines with that of controlled corridors as a response to the decrease in the availability of pasture lands, the impact of climate change and changing land use patterns.

Protection and planting of trees

Protection and tree planting was the second most common adaptation strategy, reflecting the successful regreening of the Sudano-Sahelian zone discussed earlier. Seven of the eight communities reported to protect or plant trees (Fig. 8.3). Rampant deforestation and cutting of trees by people of the area resulted in a shortage of fuelwood and other forest products as a response to which people started planting trees. Empirical evidence has shown that increasing fuelwood shortage leads to more time to collect fuelwood from communal woodlands or forests and this provides an incentive for planting trees (Arnold *et al*., 2003; Cooke *et al*., 2008). Additionally, tree protection and planting is one of the common government and non-government organization (NGO) campaigns in Niger (Pender and Ndjeunga, 2008) and such programmes have largely been driven by alarming deforestation. In addition to fuelwood, protected and planted trees also are used for animal browses and as windbreaks. The new tree-related livelihoods that communities reported to have started are firewood and charcoal-burning trading, which in part were caused by changing climate. These new livelihoods have been part of response to climate change and have increased the demand for tree products.

Water harvesting and water development

Four of the eight communities reported to have increased use of zaï, a half-moon water basin constructed to trap rainwater (Fig. 8.3). Zaï technology, first invented in Burkina Faso by a farmer, has been promoted in the Tahoua region. It is estimated that about 9000 ha of degraded lands in Tahoua have been rehabilitated using zaï (Reij and Steeds, 2003). A study by the World Bank (2009) showed that though zaï increases crop yield by 24% and reduces production risks, its annual maintenance cost (24,000 CFA francs) is higher than its returns (10,000 CFA francs) per year. Owing

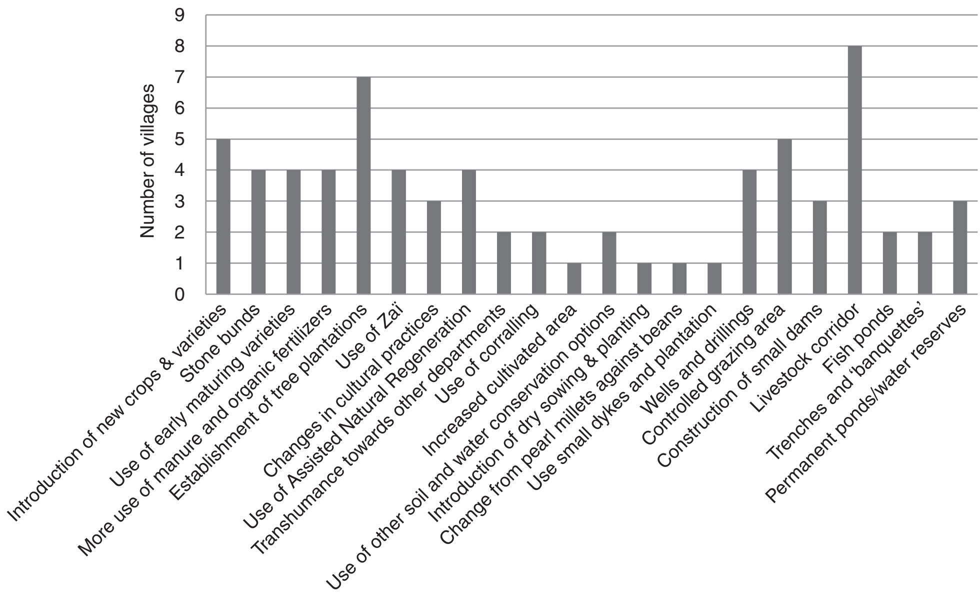

Fig. 8.3. SLWM strategies in response to climate changes.

to this and other factors, the adoption rate of zaï was only 9.5% (World Bank, 2009).

None of the eight communities reported to have used irrigation as an adaptation to climate change, suggesting a poor uptake of the most crucial practice that will enhance adaptation to climate change. Household level data showed, however, that 4.4% of the household in Tahoua used irrigation. At a national level, it is estimated that 27% of irrigable area is used for irrigation. Given the large share of land under the Sahara desert (77%) and drylands (24%) (FAOSTAT, 2007), irrigation development is key to addressing food insecurity that the country has been experiencing frequently.

Use of improved varieties and new crops

Improved crop varieties provide one of the key technologies for addressing climate change – especially in areas where rainfall is expected to be more erratic or to decrease (Lobell *et al.*, 2008). Four of the eight communities reported to have used early maturing varieties as an adaptation to climate change. Household level data also showed that 47% of households who responded to climate change used improved crop varieties.

Communities also reported to grow new crops as part of adaptation to climate change. Five of the eight communities reported to grow new crops including horticultural crops. Household-level data showed, however, that only 20% of households that adapted to climate change switched to new crops. Communities reported to switch from cotton and fruit trees to onion and other vegetables, such as sweet potato, cassava, onion, beans. Some of these crop types are more drought-tolerant than the crop replaced while some – notably vegetables – require more water and irrigation. The switch to vegetables presents an interesting case, yet contrary to expectation of switching from less drought-tolerant to more drought-tolerant crops. In all cases, farmers switching to vegetables had some form of irrigation. The trend is a reflection of the impact of market access and tendency to move to high-value crops as a strategy

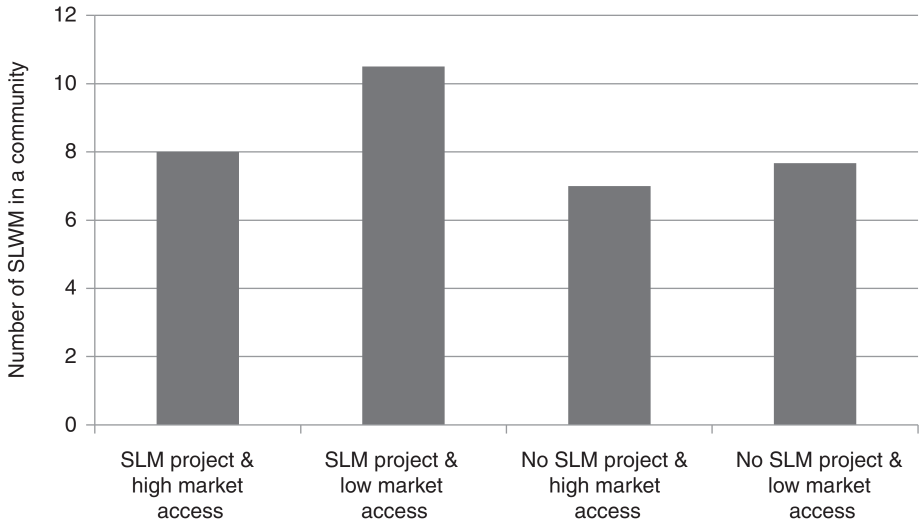

Fig. 8.4. SLWM practices adopted in response to climate change across villages with and without SLWM projects and in low and high market access.

to intensify and maximize returns to the increasingly scarce land resources.

Soil fertility management practices

Manure application was reported as an adaptation strategy by four out of eight villages that participated in this study (Fig. 8.3). This is comparable to a household survey study by the World Bank (2009), which showed that 43% of plots received organic fertilizer (which is largely manure). Manure is bulky and farmers tend to apply more of it on plots closer to homesteads and less on plots farther away – leading to what is termed as the soil fertility gradient, where plots closer to homesteads are more fertile than those farther away. No community reported to use fertilizer as an adaptation strategy. The household-level data also showed that only 0.1% of farmers used fertilizer in 2009 but a 2008 survey showed that 18.3% of the plots received fertilizer (World Bank, 2009). Generally the use of soil fertility management practices as an adaptation strategy was low in Niger. This suggests the need to promote soil fertility management practices as adaptation strategies.

8.4.3 Impact of market access and presence of SLWM projects on adaptation to climate change

We compared the number of SLWM adopted across villages with and without SLWM projects and with low and high market access. Fig. 8.4 shows the average number of SLWM practices adopted is comparable across villages in remote areas and those in high market access and between villages with and without SLWM projects. There is only a slightly larger number of SLWM practices in villages with SLWM projects but located in low market access areas. These results are contrary to expectations and could be due to the diffusion of these technologies or presence of non-project programmes that also promote SLWM projects. For example, it is possible that government programmes that have been running countrywide tree planting and other SLWM practices could have led to the widespread adoption of SLWM practices. Household-level data will be used to verify these results. Non-SLWM strategies were adopted in response to climate change (Fig. 8.5). Petty trade migration of men and consumption of non-traditional foods were

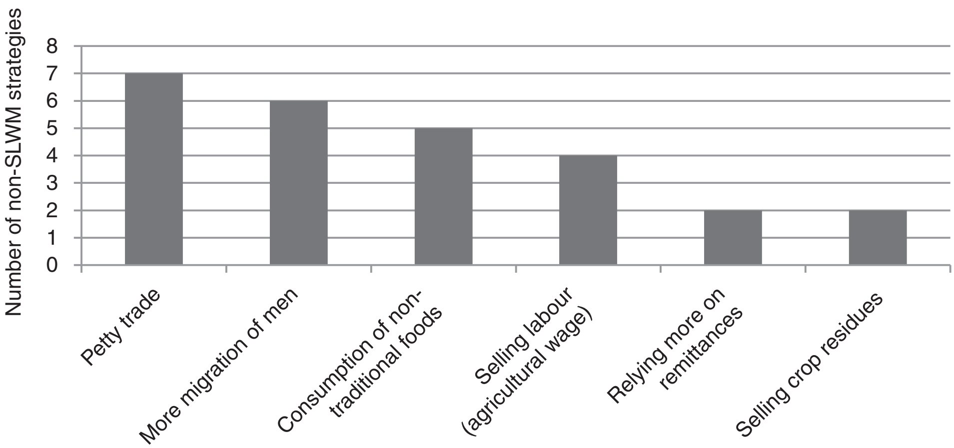

Fig. 8.5. Non-SLWM strategies adopted in response to climate change.

the most important non-SLWM strategies. Others include selling labour, remittances and selling of crop residues. These results underscore the importance of looking beyond SLWM for adaptation strategies. In particular, petty trade appears to be a practice likely to help communities to adapt to climate change by diversifying income sources.

In summary, there have been adaptations within existing activities as well as the adoption of new activities in almost all locations. Pastoral communities have used livestock corridors and have increased controlled grazing, both of which have not been common in the transhumant livelihoods. Protection and planting of trees has been a particularly common practice across all communities. Of concern is the limited use of irrigation as an adaptation strategy. This is particularly a major problem that increases risks of crop production in dry areas. Overall the community-level discussions show a variety of adaptation strategies together, which show the capacity of communities to adapt to climate change, albeit within a host of constraints that limit the level and effectiveness of adaptation.

8.4.4 Adoption of climate change smart land management practices

Integrated land and water management practices have been shown as key to effective adaptation to climate change in dry areas (Bationo and Buerkert, 2001; Pandey *et al*., 2003). Among land management practices, those that increase soil carbon also enhance moisture-holding capacity, improve biological activities and provide other benefits (Lal, 2004) and they consequently reduce climate-induced production risks. For example, a study in semi-arid areas in Kenya showed that mulching could increase the length of growing period from 110 to 113 days (Cooper *et al*., 2009). Empirical evidence has also shown a synergistic relationship among SLWM practices, i.e. holding all else constant, a household that uses more than one SLWM is likely to have better adaptation than using only one SLWM practice. For example, Bationo and Buerkert (2001) observed that water and nutrient management increased water-use efficiency and yield response to fertilizer when land and water management were combined. On a long-term soil fertility experiment in Kenya, Nandwa and Bekunda (1998) observed that plots receiving crop residues, fertilizer and manure registered the highest maize yield many years after the start of the experiment compared to plots receiving the recommended or higher fertilizer doses. Other studies have also shown similar results (Vanlauwe and Giller, 2006; Tittonell *et al*., 2008).

Adoption of early maturing or drought-resistant crop varieties also enhances adaptation to climate change (Lobell *et al.*, 2008). New efforts to develop high-temperature-tolerant crop varieties are currently underway (Anderson *et al.*, 2004). Likewise, crop varieties that are resistant to climate-induced pests and diseases will also enhance adaptation to climate change. Agronomic management practices such as changing the time of the planting season to reflect the new climatic patterns and other improved technologies will generally enhance adaptation to climate change.

Hence the climate-change smart land management practices for crop production are those that integrate land and water, enhance soil carbon, and use crop varieties adapted to drier conditions and higher temperatures. Additionally, a combination of organic and inorganic soil fertility management practices enhances adaptation to climate change and increases crop productivity.

Climate change smart livestock management practices are also related to the land management practices for crops. Likewise, livestock breeds for the dry areas should tolerate the expected higher temperatures and reduced water availability. Pasture and rangeland management fall into the category of crop management practices and what has been discussed above also applies to pasture management. Grazing regimes should ensure enhanced productivity of livestock. For example, rotational grazing has been shown to increase cattle live weight by up to 63% (Walton *et al.*, 1981).

The land management practices adopted in response to climate change show limited integrated land and water management. Of the top five SLWM practices used to adapt to climate, only 17% of farmers reported to have used SLWM. No farmer reported to have used fertilizer in combination with organic soil fertility management regardless of the reason of use (Table 8.5). This shows limited integrated soil fertility management practices. These results are consistent with those of Benhin (2006), Kabubo-Mariara and Karanja (2006), and Yesuf *et al.* (2008) who found limited use of SLWM practices as adaptation strategies. Water management is particularly limiting. This suggests the need to promote integrated land management practices that can effectively enhance adaptation.

Table 8.5. Adoption rates of land and water management practices in Niger.

Variable	% Adopted
Irrigation	4.4
Alley cropping	15.5
Fertilizer and organic fertilizer	0.0
Animal manure	1.0
Fertilizer	0.1
Bench terraces	0.6
Crop rotation	0.4
Vegetative strips	1.2
Fanya chini[a]	17.7
Fanya juu[b]	0.1
Improved fallow	0.6
Crop residue incorporation	0.1
Mulching	6.4
Zaï pits	0.4
Rotational grazing	0.4
Restricted grazing	0.4
Resting of grazing land	2.5
Water harvesting	0.4

[a] *Fanya chini* is a terrace in which soil is thrown onto the lower side of the terrace. [b] *Fanya juu* is a terrace in which soil is thrown onto the upper side of the terrace.

8.4.5 Vulnerability and reasons for not responding to climate change

Farmers were asked to state reasons for not responding or lack of additional desired response to climate change. The major reason given for not responding to climate change or not more effectively responding was lack of money (Table 8.6). Over 50% of the households reported lack of money as the reason for failing to take adaptive strategies to climate change or not responding more effectively. This confirms the vulnerability of the poor and the high cost of some of the adaptation strategies used by farmers.

Lack of access to inputs was the second most important reason for not adapting to climate change. This suggests greater vulnerability for farmers in remote areas where access to agricultural inputs such as early

Table 8.6. Reasons for not responding to climate change.

Reason	Respondents (%)
No money	53.5
No inputs	21.3
No access to credit	17.5
Shortage of labour	3.7
No information on appropriate adaptations	2.1
No access to land	2.1

maturing crop varieties is lower. Lack of credit was the third most important reason for failing to adapt to climate change. This gives further evidence that the poor – who have limited access to credit – are more vulnerable to climate change. The results also suggest that improving access to credit will enhance adaptation to climate change. Shortage of labour was the fourth most cited reason for not responding to climate change. The results imply the labour intensiveness of the SLWM management required for adaptation to climate change and the need to develop labour-saving technologies for SLWM. Lack of information on appropriate adaptation strategies was the fifth most important reason for failing to adapt to climate change. This is to be expected given the level of uncertainty in predicted and perceived climate change and the lack of a coordinated and operational strategy on climate change adaptation in agriculture. This also underlines the weak agricultural extension services to provide advisory services on adaptation to climate change, a problem that is common in SSA, where agricultural advisory services are still focused on crop production.

Lack of land was also the fifth most cited reason for not responding to climate change. This is part of the reason for the increasing trend of horticultural crops that was reported as part of adaptation to climate change.

Below we use a multivariate approach to analyse the variables influencing response to climate change. We analysed the determinants of adaptation to long-term change in precipitation, variability of rainfall and temperature. We also analysed the drivers of adaptation to any of the three types of long-term climate change. For brevity, we only report the determinants of response to any type of long-term climate.

8.4.6 What drives the adoption of SLWM practices?

The analysis above showed the drivers of response to climate change. Below, we discuss the determinants of adoption of SLWM practices, which as discussed above enhances adaptation to climate change. To better understand the farmers' behaviour on where they use a given land management practice, we first examine the influence of plot-level characteristics on adoption of SLWM. We then focus our discussion on policy-relevant drivers.

Plot characteristics

Plot characteristics were the most important factors in influencing the use of land management practices. Mulch is likely to be used on plots with a finer soil texture and irrigation is more likely to be done on clay soils than on sandy soils (Table 8.7). A third of plots in Niger had sandy soil texture and another third had clay texture. Additionally, irrigation is more likely to be used on plots with high soil fertility than on plots with poor soil fertility. This suggests irrigation was targeted to plots with finer texture and to fertile plots to avoid percolation that loses water and to ensure maximum returns on scarce water resources.

Farmers were more likely to use compost on plots with poor or moderate soil fertility than on plots with high soil fertility. Additionally, farmers were more likely to use mulching on plots with poor soil fertility than on very fertile plots. These results suggest farmers use organic soil fertility management practices to address poor soil fertility. In summary, plots with sandy soils are less likely to be irrigated, while plots with poor soil fertility are more likely to receive compost and mulch as an attempt to address their poor fertility. These results suggest that farmers with poor plots are less likely to effectively adapt to climate change by combining land and water management practices.

Physical capital

Physical capital endowment generally had a favourable influence on the adoption of SLWM practices. Value of farm equipment is negatively associated with a propensity to invest in *fanya juu* (see Table 8.5) and irrigation but is positively associated with mulching. The negative association with *fanya chini* could be due to its high labour intensity, which makes it unattractive. Livestock did not have a significant impact on use of most land management practices in Niger. A similar study in Nigeria and Uganda showed that livestock had a favourable impact on use of SLWM, underscoring the positive crop–livestock interaction observed in other studies and the potential for sustainable land and water management for households with both crop and livestock production. Defoer *et al*. (2000) and Ryan and Spencer (2001) also showed that farmers with livestock and crops are able to enhance soil fertility more sustainably than those growing crops or keeping livestock only. The weak impact of livestock on SLWM in Niger could be due to the large endowment of livestock in almost all households sampled.

Farm area is positively associated with irrigation, suggesting that large-scale farmers are more likely to have access to irrigation than smallholder farmers. This implies a high vulnerability of small farmers to climate change.

Land tenure

Plots under customary land tenure were more likely to be irrigated than plots under leasehold. The results are consistent with other studies in SSA (Platteau, 1996; Toulmin and Quan, 2000; Deininger, 2003), which showed comparable or better investments on plots under customary tenure to those under formal land title. These results provide further evidence of the high-security perception that farmers attach to plots held under customary tenure. *Fanya chini* is more likely to be practised, however, on plots held under leasehold than those held under customary tenure. This could be an attempt by farmers with leasehold tenure to enhance long-term tenure security through long-term investments.

Human capital endowment

Female-headed households were less likely to use mulching and *fanya chini* than male-headed households but more likely to use compost. The results suggest the limited resources that female-headed households have, which makes adoption of some practices untenable. It is also possible that the female-headed households resort to composting, a practice that is also labour intensive but more amenable for women, who manage the household refuse used for composting, than for men.

Education generally has a negative impact on adoption of SLWM practices. Consistent with other studies, the household head level of education generally has negative or no significant association with land management practices. This is due to the high opportunity cost of highly educated labour, which makes it more costly to adopt labour-intensive land management practices. These results underscore the high labour intensity of SLWM and the consequent lower propensity to be adopted by households with high labour opportunity cost. Surprisingly, it is only *fanya chini* that is positively associated with secondary education. Non-farm income reduces the probability of using mulching and *fanya chini*. As argued above, this could be due to the competition for labour between farming and non-farm activities. Overall, these results confirm the high labour intensity of SLWM practices, and the weak labour market that makes family labour key to the adoption of labour-intensive land management practices. The low adoption of the labour-intensive SLWM practices also reflects the tendency of households to use their own labour instead of farm equipment to do long-term land investments. The results also

Table 8.7. Determinants of adoption of land management practices (marginal effects).

Variable	Alley cropping	Compost	Mulch	*Fanya chini*	Irrigation
Colour and texture of soil (c.f. sandy soils)					
Brown	–0.073**	0.139***	0.062*	–0.090***	–0.034***
Grey	–0.065*	0.132**	0.196***	–0.103***	–0.034***
Red	0.022	0.042	–0.006	–0.075*	–0.034***
Black	0.085*	0.057*	–0.018	0.009	–0.011
Clay	–0.039*	0.008	0.061**	–0.061***	0.052***
Soil fertility (c.f. highly fertile)					
Moderate	–0.026	–0.048***	0.011	0.073**	–0.01
Poor	0.027	–0.043*	0.090***	0.017	–0.034***
Status of soil erosion (c.f. no soil erosion)					
Mild	0.035	0.011	0.013	–0.098***	–0.002
Severe	–0.063	–0.013	0.02	0.023	0.082*
Household physical capital endowment					
Ln(value of equipment FCFA)	–0.007	0.013**	0.000	–0.014***	–0.005*
Ln(value of livestock FCFA)	0.004	–0.003	–0.002*	0.001	0.001
Ln(plot area, ha)	0.060***	0.018*	0.009	0.029*	–0.01
Ln(farm area, ha)	–0.038**	0.015	–0.021	0.011	0.026***
Land tenure (c.f. customary)					
Leasehold	0.018	0.060**	–0.005	0.123***	–0.013*
Human capital					
Ln(household size)	–0.085	0.133**	–0.098**	–0.038	–0.011
Female-headed household	0.036	–0.116***	0.170**	–0.181***	0.067
Ln(number of male household members)	0.021	–0.181***	0.110**	0.028	–0.049*
Ln(number of female household members)	0.086*	–0.069	0.063**	–0.011	–0.006
Level of education of household head (c.f. no formal education)					
Primary	–0.146***	–0.132***	–0.059***	–0.176***	0.044
Secondary	0.072**	–0.074***	–0.097***	0.059**	0.012
Non-farm	–0.047	0.213***	–0.060***	–0.072**	0.062*
Membership to economic and other groups					
Production	0.09	–0.130***	0.278***	0.007	–0.013
Religious	0.014	–0.072***	–0.054***	–0.135***	–0.012
Access to rural services					
Ln(distance to agricultural markets, km)	0.004	0.001	–0.047***	0.032**	–0.001
Access to climate information	0.042	–0.143***	0.003	0.015	0.018
Access to extension services	–0.058**	0.037	–0.075***	–0.089***	0.031*
Access to formal credit	–0.031	0.013	0.067***	0.014	0.000
Access to non-formal credit	–0.017	–0.041**	–0.004	–0.077***	–0.017**
Ln(distance to plot, km)	–0.058***	0.034***	0.002	–0.001	–0.023***
Presence of SLWM project	0.099*	–0.088***	–0.02	–0.216***	–0.413***
High market access	0.007	0.150***	–0.175***	0.192**	0.468***
N	609	609	609	609	834

Note: For brevity, village fixed effects are not reported.

reveal the vulnerability of female-headed households with limited resources.

Membership of production groups is associated with mulching but negatively associated with composting. This is probably due to the labour exchange done for mulching and tendency to implement composting at household level owing to its slow process. Composting generally is done by dumping household residues into pits for a considerable length of time and hence is unlikely to be done by a production group. Religious groups generally have a negative or no impact on the propensity to adopt SLWM practices. This is due to their non-productive orientation.

Collective action through group membership has often been found to provide farmers greater access to information, whether through extension, NGOs, projects or other farmers. In cases where we observe a negative association of production group membership with the adoption of a given SLWM practice, the reason could be the weak capacity of the groups to promote SLWM. This suggests the need to enhance their capacity through rural development programmes that use farmer groups – such as community driven development (CDD). These groups should promote advisory services on land management practices and adaptation to climate change.

Access to rural services

Proximity to agricultural markets increases the probability to adopt mulching but reduces the propensity to adopt *fanya chini*. The high labour intensity of *fanya chini* could explain its low propensity to be adopted in areas closer to agricultural markets where labour cost is likely to be higher. The propensity to use irrigation is also higher in areas closer to agricultural markets. This association is not significant, however, at $p = 0.10$ but suggests that farmers in remote areas are less likely to have access to irrigation. Similar results were observed in Nigeria (World Bank, 2009).

Access to extension services increases the probability of adopting irrigation but reduces the probability to adopt mulching and *fanya chini*. These results suggest that extension services are weak in providing advisory services on organic soil fertility management practices as observed by Banful *et al*. (2009) and Nkonya *et al*. (2010) in Nigeria, and Benin *et al*. (2009) in Uganda. As expected, the presence of SLWM projects in a village increased the probability to adopt alley cropping. The presence of an SLWM project reduces the propensity to use *fanya chini*, irrigation and composting, however. The ambiguous impact of SLWM projects could be due to their orientation. Many SLWM projects in Niger have been promoting tree planting, a practice that is compatible with alley cropping.

These results reveal the apparent complementarity of traditional extension services, which seem to focus on promoting irrigation and SLWM projects, which in turn seem to be focused on alley cropping and tree planting. The results underscore the importance of multiple providers of extension services that have complementarity in the provision of different types of technologies. Current efforts in Niger of involving NGOs and projects to provide extension services provide the opportunity to address the weaknesses of the traditional agricultural extension services. Yet, there is need to increase the capacity of agricultural extension services to provide SLWM practices.

8.4.7 Impact of land management practices on agricultural productivity and production risks

As expected, irrigation, alley cropping and mulching all increase crop productivity (Table 8.8). Additionally, alley cropping reduces production risks significantly. Irrigation, mulching and *fanya chini* also reduces production risks but their influence is not significant, at $p = 0.10$. The large favourable impact of irrigation on crop productivity confirms the importance of land and water management practices to enhance productivity in Niger.

The results underscore the significance of organic soil fertility management and water management in increasing crop

Table 8.8. Crop production function (structural and reduced form models) and risk function (deviation from conditional mean yield).

Variable	Structural models		Reduced model	Variance function (risk function)
	OLS	IV-2SLS	OLS	
Endogenous variables				
Land management practices				
Alley cropping	0.061	5.881**		–0.132***
Compost	–0.171	1.987		0.048
Fanya chini	0.001	1.757		–0.043
Mulching	0.05	5.068**		–0.078
Irrigation	0.455**	9.628		–0.011
Group membership				
Production group	–0.213	–0.79		–0.076
Religious group	0.228**	0.547		–0.054
Access to rural services				
Climate information	0.063	3.017		–0.018
Agricultural extension	–0.076	0.832		0.005
Formal credit	–0.210**	–0.637		0.031
Informal credit	–0.200***	–1.077		–0.076**
Exogenous explanatory variables				
Plot soil colour and texture (c.f. sandy soils)				
Brown	–0.099	0.71	–0.091	0.090*
Grey	–0.403**	–0.284	–0.418**	–0.025
Red	0.298**	0.34	0.326**	0.088
Black	–0.398***	–0.362	–0.342***	0.105**
Clay	–0.718***	–1.028**	–0.661***	0.110***
Soil fertility (c.f. very fertile)				
Moderate fertility	0.004	–0.057	0.012	–0.019
Poor fertility	–0.074	–0.535	–0.06	–0.009
Severity of erosion (no soil erosion)				
Mild erosion	0.008	–0.807	0.008	0.028
Severe erosion	0.1	–0.633	0.119	–0.043
Capital endowment				
Ln (value of equipment, FCFA)	0.070***	0.193*	0.057***	0.008
Ln (value of livestock, FCFA)	0.016**	–0.035	0.019***	0.000
Ln (plot area, ha)	–0.335***	–0.698***	–0.336***	0.063***
Ln (farm area, ha)	–0.406***	0.052	–0.389***	–0.033
Leasehold land tenure (c.f. customary)	0.028	0.129	0.007	0.078**
Human capital				
Ln (household size)	0.402**	0.849	0.380**	–0.078
Ln (female household members)	–0.096	0.405	0.028	–0.048
Ln (male household members)	–0.119	–0.474	–0.071	0.038
Ln (female family members)	–0.177	0.057	–0.224*	0.049
Education of household head (c.f. no formal education)				
Primary	–0.231	–1.42	–0.199	0.217*
Secondary	–0.114	0.089	–0.063	0.022
Non-farm activity	–0.455***	–0.363	–0.439***	0.019
Access to rural services				
Ln (distance to agricultural market)	0.125***	0.24	0.109***	0.024
Ln (distance to plot)	0.05	0.203	0.029	–0.013
Presence of SLWM project	–0.123	1.650*	–0.164	0.057
High market access	–0.128	–1.674**	–0.225	0.024
Constant	9.083***	3.039	9.194***	0.248*
N	916	916	916	916

productivity and reducing climate-related production risks. The results are also consistent with biophysical studies, which show that organic soil fertility management practices increase moisture storage capacity, which in turn addresses yield variability resulting from drought and other climate-related changes (Bationo and Buerkert, 2001, Bationo *et al*., 2007).

Contrary to expectations, sandy soils tend to have higher productivity than clay, black and grey soils. It is only the red soils that have greater yields than sandy soils. The higher productivity on sandy plots could be due to other factors not captured by the covariates included in the study. More research is required to better understand the reason behind these puzzling results.

As expected, the value of productivity assets and livestock is positively related to agricultural productivity. The results imply the low yields of poor farmers. Plot and farm area are both negatively associated with productivity, suggesting the inverse area–productivity relationship that has been observed in other studies (Lamb, 2003). This suggests higher productivity of smallholder farmers owing to their greater labour and other input investment on their small plots. Related to this, family size is positively related to productivity. Plot size is also positively related to production risks. Leasehold is positively associated with production risks suggesting that farmers holding land under customary tenure use production technologies with lower risks. This further shows the superiority of customary land tenure over leasehold.

Non-farm activities are negatively related to crop productivity, further underscoring the poor labour market that leads to competition for family labour between crop production and non-farm activities. As stated above, however, non-farm activities are important for coping with climate change risks. Hence the results suggest the need to develop labour-saving technologies to ensure that farmers with non-farm activities could still use SLWM technologies to get higher yields.

Agricultural extension services did not have a significant impact on crop productivity. This could be due to inclusion in the model of land management practices, through which the agricultural extension services improve productivity. The results also reflect, however, the weak impact of extension services, which as seen previously only affected positively adoption of irrigation (Table 8.8). The presence of an SLWM project in the village was positively associated with crop productivity.

Distance from agricultural markets and households in low market areas reported higher crop productivity. This could be due to the greater investment in crops by farmers in remote areas due to their lack of alternative livelihoods.

In summary, the results show that organic soil fertility and irrigation increase crop productivity and reduce production risks. Our results also show higher crop productivity for households with a greater value of productive assets and livestock, suggesting the low productivity of poor farmers and the need to design production technologies affordable to poor farmers. We also observe the inverse productivity and farm area relationship, suggesting the greater potential of poor farmers to invest more inputs in their small plots. Consistent with this, our results also reveal the weak rural labour market, which lead to lower yields for households with non-farm activities. This points to the need to develop labour-saving technologies.

8.4.8 The way forward according to rural communities

Strong local institutions and farmer groups are required to collectively manage natural resources and effectively respond to climate change. Indeed, community-level actions are required to enhance collective adaptation (Huq and Reid, 2007; Aalst *et al*., 2008; Ayers and Forsyth, 2009). Villages were asked to state the steps they have taken to collectively enhance adaptation to climate change. There were only a few local adaptation strategies initiated at the local level by local actors, except for the establishment of livestock corridors. By-laws requiring community members not to cut trees or to cut trees with the authorization of forestry agents was enacted by local governments in all the eight villages. Compliance and enforcement to regulations remain a challenge, however, and calls for stronger institutions and community groups to enhance collective natural resource management. The community initiatives to collectively manage natural resources, which have been precipitated by climate change and other socio-economic changes, indicate the need for taking bold steps to support the community initiatives. These initiatives provide an opportunity for the National Adaptation Program of Action (NAPA) to take advantage of the community awareness of climate change and interest in taking collective and individual actions to address land and water resources affected most by climate change and other changes. Communities realize the weaknesses in the local institutions to enact and enforce compliance with natural resource management rules. Increasing the capacity of local communities to collectively manage rangelands and water resources will require involvement of civil society organizations with a focus on natural resource management. These have been shown to increase capacity of local institutions to enact by-laws (Lind and Cappon, 2001; Berkes, 2004; Nkonya *et al*., 2008). In the NAPA, increasing the capacity of local communities to adapt to climate change is not a strong component. Even though the Niger NAPA mentions the need to strengthen the capacity of local institutions to enhance adaptation to climate change, there is little resource allocation in this area. This is one of the policy weaknesses that require significant attention in policy formulation and resource allocation.

Some statutes for natural resource management are formed across sectors and eventually give conflicting rules that create implementation challenges. For example, although the Water Code stipulates water is a public resource accessible to anyone, the Rural Code stipulates that water in a given pastoral community belongs to the community and pastoralists from other communities do not have access. This calls for coordination of different ministries and departments within the government system and other programmes that support development and management of natural resources and the environment.

Farmers were asked to give suggestions of what needs to be done to help them adapt to climate change. The most frequently reported strategy was the investment in water conservation structures (small dams and water ponds) to allow them to grow vegetables during the off-seasons and the use of soil and water conservation methods. Water harvesting includes a range of microcatchment systems, earthen bunds and other structures to capture and store runoff. Water harvesting is especially important for the semi-arid areas, where such strategies have shown significant impact on adaptation to climate change (Pandey *et al*., 2003). Six out of eight communities have used soil and water conservation techniques as adaptation strategies. In Niger, the government and donors have invested in promoting soil and water conservation methods such as zaï, half-moon, trenches, banquettes, etc. This is a major part of the government of Niger Poverty Reduction strategy to help communities cope with climate change.

According to communities, the development of an irrigation infrastructure and community-based irrigation schemes are among the adaptation strategies. The potential for irrigation could be increased significantly by promoting rainwater harvesting discussed above and by promoting small-scale irrigation systems, which have shown significant success in the semi-arid tropics in other countries. For example, ICRISAT has promoted more than 2500 small-irrigation systems to more than eight countries in West Africa. Access to credit was requested by all communities as a means to smooth their consumption and to help cope better with climate change.

The context-specific recommendations for enhancing adaptation to climate change and reducing vulnerability were drawn from the study. The recommendations are: (i) develop and promote climate change-smart practices; (ii) create a conducive environment for farmers to adopt SLWM; (iii) strengthen local natural resource management institutions and harmonize strategies;

and (iv) build strong national policies that support scaling up of SLWM.

Notes

[1] The weather stations of Abalak, Birnin Konni have 30 years of weather data.

References

Aalst, M.A., Cannon, T. and Burton, I. (2008) Community level adaptation to climate change: the potential role of participatory community risk assessment. *Global Environmental Change* 18, 165–179.

Abdoulaye, T. and Abasse, T. (2005) *Assessment of Joint Forest Management in Niger, Nigeria and Ghana*. Executive final report, AFORNET GRANT No. December 5, 2003, Niamey, Niger.

Abdoulaye, T. and Sanders, J.H. (2005) Stages and determinants of fertilizer use in semiarid African agriculture: the Niger experience. *Agricultural Economics* 32, 167–179.

Adam, T., Reij, C., Abdoulaye, T., Larwanou, M. and Tappan, G. (2006) *Impacts des Investissements Dans la Gestion des Resources Naturalles (GRN) au Niger: Rapport de Synthese*. Centre Régional d'Enseignement Specialise en Agriculture (CRESA), Niamey, Niger.

Anderson, P.K., Cunningham, A.A., Patel, N.G., Morales, F.J., Epstein, P.R. and Daszak, P. (2004) Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. *Trends in Ecology & Evolution* 19 (10), 535–544.

Arnold, M., Köhlin, K., Persson, R., and Shepherd, G. (2003) *Fuelwood Revisited: What Has Changed in the Last Decade?* Occasional Paper 39. Center for International Forestry Research, Jakarta, Indonesia.

Ayers, J. and Forsyth, T. (2009) Community-based adaptation to climate change: responding to poverty and vulnerability. *Environment* 51, 22–31.

Banful, B., Nkonya, E. and Oboh, V. (2009) *Constraints to Fertilizer Use in Nigeria: Perspectives and Insights from the Agricultural Extension Service.* Nigeria Strategy Program Policy Brief #6. International Food Policy Research Institute (IFPRI), Abuja, Nigeria.

Bationo, A. and Buerkert, A. (2001) Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems* 61, 131–142.

Bationo, A., Waswa, B., Kihara, J. and Kimetu, J. (2007) *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities.* Springer, Dordrecht, Netherlands.

Beintema, N. and Stads, G. (2011) *African Agricultural R&D in the New Millennium. Progress for Some, Challenges for Many*. IFPRI Food Policy Report, Washington, DC.

Benhin, J. (2006) *Climate Change and South African Agriculture: Impacts and Adaptation Options*. CEEPA Discussion Paper No. 21. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Benin, S., Nkonya, E., Okecho, G., Randriamamonjy, J., Kato, E., *et al*. (2009) *Impacts of and Returns to Public Investment in Agricultural Extension: The Case of the National Agricultural Advisory Services (NAADS) Program of Uganda*. Mimeo, International Food Policy Research Institute, Washington, DC.

Berkes, F. (2004) Rethinking community-based conservation. *Conservation Biology* 18, 621–630.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A. *et al*. (2007) Africa. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, pp. 433–467.

Chappell, A. (1996) Modelling the spatial variation of processes in the redistribution of soil: digital terrain models and 137Cs in SW Niger. *Geomorphology* 17 (1/3), 249–262.

CNEDD (2005) *State of Environment in Niger*. http://www.cnedd.ne (Accessed 28 July 2015).

Cooke, P., Köhlin, G. and Hyde, W. (2008) Fuelwood, forests and community management: evidence from household studies. *Environment and Development Economics* 13, 103–135.

Cooper, P.J.M., Rao, K.P.C., Singh, P., Dimes, J., Traore, P.S., *et al*. (2009) Farming with current and future climate risk: advancing a 'hypothesis of hope' for rainfed agriculture in the semi-arid tropics. *Journal of SAT Agricultural Research* 7, 1–19.

Defoer, T., Budelman, A., Toulmin, C. and Carter, S. (2000) Building common knowledge: participatory learning and action research. In: Defoer, T. and Budelman A. (eds) *Managing Soil Fertility in the Tropics. A Resource Guide for Participatory Learning and Action Research.* Royal Tropical Institute, Amsterdam, p.73.

Deininger, K. (2003) *Land Policies for Growth and Poverty Reduction*. World Bank Policy Research Report. World Bank, Washington, DC and Oxford University Press, Oxford, UK.

FAOSTAT (2007) http://faostat.fao.org/ (Accessed 21 March 2011).

Henao, J. and Baanante, C. (2006) *Agricultural Production and Soil Nutrient Mining in Africa: Implications for Resource Conservation and Policy Development.* International Fertilizer Development Center, Muscle Shoals, Alabama.

Hoffman, I. (2004) Access to land and water in the Zamfara Reserve: A case study for the management of common property resources in pastoral areas of West Africa. *Human Ecology* 32, 177–105.

Huq, S. and Reid, H. (2007) Community based adaptation: a vital approach to the threat climate change poses to the poor. *IIED Briefing Paper 17005*. International Institute for Environment and Development (IIED), London.

Jauffret, S. (2009) *Cadre stratégique d'investissement national pour la gestion durable des terres au Niger*. Ministere de l'Environnement et de la Lutte Contre la Desertification.

Just, R.E. and Pope, R.D. (1979) Production function estimation and related risk considerations. *American Journal of Agricultural Economics* 61, 276–284.

Kabubo-Mariara, J. and Karanja, F. (2006) *The Economic Impact of Climate Change on Kenyan Crop Agriculture: A Ricardian Approach*. CEEPA Discussion Paper No. 12. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, South Africa.

Lal, R. (2004) Soil carbon sequestration to mitigate climate change. *Geoderma* 123, 1–22.

Lamb, R.L. (2003) Inverse productivity: land quality, labor markets, and measurement error. *Journal of Development Economics* 71(1), 71–95.

Lind, J. and Cappon, J. (2001) *Realities or Rhetoric? Revisiting the Decentralization of Natural Resource Management in Uganda and Zambia*. Acts Press, Nairobi, Kenya.

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

Mortimore, M., Tiffen, M., Boubacar, Y. and Nelson, J. (2001) *Synthesis of Long-term Change in Maradi Department, Niger, 1960–2000*. Drylands Research Working Paper No. 39e. Drylands Research, Crewkerne, UK.

NAPA (National Adaptation Programme of Action) (2006) *Niger National Adaptation Programme of Action*. Niamey, Niger.

Nkonya, E., Pender, J. and Kato, E. (2008) Who knows, who cares? The determinants of enactment, awareness, and compliance with community natural resource management regulations in Uganda. *Environment and Development Economics* 13, 79–109.

Nkonya, E., Bisong, F., Koo, J., Xie, H., Kato, E., *et al*. (2010) *SLM Advisory Services: Key Institutional, Financing, and Economic Elements for Scaling Up Sustainable Land Management in Nigeria*. International Food Policy Research Institute, Washington, DC.

Pandey, D., Gupta, A. and Anderson, D. (2003) Rainwater harvesting as an adaptation to climate change. *Current Science* 85, 46–59.

Pender, J. and Ndjeunga, J. (2008) *Assessing Impacts of Sustainable Land Management Programs on Land Management and Poverty in Niger*. Report II (Full Study Report). International Food Policy Research Institute. Mimeo, Washington DC.

Platteau, J.P. (1996) The evolutionary theory of land rights as applied to Sub-Saharan Africa: a critical assessment. *Development and Change* 27, 29–86.

Reij, C. and Steeds, D. (2003) *Success Stories in Africa's Drylands: Supporting Advocates and Answering Skeptics*. Paper commissioned by the Global Mechanism of the Convention to Combat Desertification. Vrije University and Centre for International Cooperation, Amsterdam, the Netherlands.

Reij, C., Tappan, G. and Smale, M. (2009) Regreening the Sahel: farmer-led innovation in Burkina Faso and Niger. In: Spielman, D. and Pandya-Lorch, R. (eds) *Millions Fed.* International Food Policy Research Institute, Washington, DC, pp. 53–58.

Ryan, J.G. and Spencer, D.C. (2001) *Future Challenges and Opportunities for Agricultural R&D in the Semi-arid Tropics.* International Crops Research Institute for the Semi-Arid Tropics, Andhra Pradesh, India, pp. 79.

Svendsen, M., Ewing, M. and Msangi, S. (2009) *Measuring Irrigation Performance in Africa*. IFPRI Discussion Paper 00894, International Food Policy Research Institute. Mimeo, Washington DC.

Tittonell, P., Corbeels, M., van Wijk, M., Vanlauwe, B. and Giller, K. (2008) Combining organic and mineral fertilizers for integrated soil fertility management in smallholder farming systems of Kenya: explorations using the crop–soil model FIELD. *Agronomy Journal* 100, 1511–1526.

Toulmin, C. and Quan, J. (2000) Registering customary rights. In: Toulmin J. and Quan, J. (eds) *Evolving Land Rights, Policy and Tenure in*

Africa. Department for International Development, International Institute for Environment and Development, Natural Resources Institute, London UK, pp. 207–228.

Vanlauwe, B. and Giller, K.E. (2006) Popular myths around soil fertility management in Sub-Saharan Africa. *Agriculture, Ecosystem and Environment* 116, 34–46.

Walton P., Martinez, R. and Bailey, A. (1981) A comparison of continuous and rotational grazing. *Journal of Range Management* 34, 19–21.

World Bank (2009) *Republic of Niger, Impacts of Sustainable Land and Water Management Programs on Land Management and Poverty in Niger*. Report No.: 48230-NE.

Yesuf, M., Di Falco, S., Deressa, T., Ringler, C. and Kohlin, G. (2008) *The Impact of Climate Change and Adaptation on Food Production in Low-income Countries: Evidence from the Nile Basin, Ethiopia*. IFPRI Discussion Paper 828. International Food Policy Research Institute (IFPRI), Washington, DC.

9 Sociological Significance: Enhancing Resilience to Climate Change Among Communities

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Abstract

Interesting sociological dimensions of enhancing resilience to climate change among communities were observed for formulating viable policy interventions. This chapter applied a comprehensive approach appealing to principles, methodologies, tools, validation and evaluation techniques for understanding the social dimensions of responses and adaptation to climate change. The analyses were undertaken at the individual and systems level with particular attention to the role of networks. The case studies from India revealed deeper sociological insights on i) farmers' perceptions of climate change or variability; ii) binding constraints to adaptation and vulnerability; and iii) coping mechanisms to enhance their adaptive capacity. Three case studies of the villages of Dokur, Kanzara and Shirapur in the semi-arid regions of India, complemented by comparable observations from three additional villages from the longitudinal Village Level Studies panel data (ICRISAT 2014), highlighted significant findings. The first is that farmers perceive climate variability rather than climate change. Second, the critical constraints are not just the lack of access to financial resources, but that human and social capital as well as institutional and governance challenges are equally binding. Lastly, collective action and institutional arrangements effectively mediate the adaptive capacity and resilience of communities to climate change.

9.1 Introduction

Coping with current variations and future long-term changes of climate along with assessing vulnerability at the grass roots demands a clear understanding of the complex social structure and its future scenarios (Bohle *et al*., 1994). In the marginalized communities such as the semi-arid tropical environment, adaptation is usually considered pertinent in overcoming the negative impacts of climate that are highly dependent on the natural resource and environment (Adger, 2003). As understood by many researchers, efficient adaptation depends on a variety of interrelated factors, including farm-level conditions, efficient technologies and practices, along with the sustainable livelihood framework for the region. The essence of a social set up, including socio-cultural and institutional arrangements, needs to be studied because it determines the way to adapt, willingness to adapt and even availability and access of options. Literature also reveals that the perception or awareness of climate change and taking adaptation decisions are influenced by different socio-economic and environmental factors (Hassan and Nhemachena, 2008; Semenza *et al*., 2008). The vulnerability of the community is the susceptibility of a community or an individual to the harmful

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impacts of disturbance in climatic conditions and weather patterns. The semi-arid ecosystems of Asia are characterized by extreme rainfall variability, recurrent but unpredictable droughts, high temperatures and low soil fertility (Bantilan *et al*., 2006). Adaptations are actions and adjustments undertaken to maintain the capacity to deal with stresses induced as a result of current and future external changes. At the micro-level, these are done through developing and/or strengthening institutions, social practices, and approaches in dealing with problems and uncertainty. The effectiveness of adaptation strategies for climate change depends on the social acceptability, the institutional constraints on adaptation and a place in the wider landscape for economic development and social evolution (Adger *et al*., 2003).

The strategies through external interventions help to reinforce livelihood practices and local rural institutions by supplying four types of support – informational, technological, financial and leadership – that reduces the costs of collective action (Agrawal, 2008). Social institutions can also influence the adaptive capacity and vulnerability by: (i) channelling the delivery of resources both within the community and from external sources; (ii) mediating farmers collectively towards a common goal; and (iii) influencing the grass-root governance of dealing with climatic impacts and vulnerability. The success of adaptation practices depends on the links of individuals, changes among households and communities with the institutions, as well as the links between the institutions. Connections between local and higher-level institutions allow women, men and youth of a given community to leverage their membership of local institutions for gains from outside the community (Agrawal, 2008). This interconnection is often lacking, among national and local institutions and between relief and development programmes. The approach therefore entails a consideration of the role of social institutions in reducing vulnerability, how these institutions are challenged and changed over time, and the wider political economy of their evolution (Adger, 2000). Growing scientific and governmental acknowledgement that human activity and social behaviours are key drivers of global climate change underscores the critical role of social science in advancing, understanding and designing strategies for responding to global climate change. Sociological analysis of climate has its own niche in climate-change research because by default research tends to be more concentrated on the natural sciences and fails to address the biophysical environment impact on the real people, and social science experts are seldom consulted. It may also be true that social scientists tend not to seek collaborations with, and are often uninformed about, major research programmes on climate change. In research activities, an inter-disciplinary approach is seldom followed. The results from the individual community do not tend to be informed by the insights and resources available from the others.

9.2 Principles, Tools, Approaches, Validation and Evaluation of Sociological Approaches

From the comprehensive review report of Harvey *et al*. (2013), sociological studies need to consider three aspects: individuals, systems and networks. The principles considered in the sociological studies include stakeholder participation, the process of facilitation, and knowledge consideration and management. Under stakeholder participation, there is a need for involvement of individuals from diverse backgrounds to get a composite view and avoid bias in information gathering. For process facilitation, bridging organizations and simulating collaboration, and building trust will provide information on a common vision and platform. There should be a convergence of available narratives across groups, welcoming different views and ideas, integrating an understanding of social and environmental dimensions and changes, and including local knowledge.

The tools and approaches used, knowledge management, capturing lessons, interaction and simulation exercises are to be

Table 9.1. Key components in the sociological analysis of climate change.

	Individuals	Systems	Networks
Principles			
Stakeholders Participation	Avoid participation of higher authorities or dominant individuals. Skilfully interact with participants through awareness of various goals	Involvement of individuals from varied members to get a composite view; deficiency of skills could be an obstacle to full and active participation	
Process of facilitation	Efficient facilitator, trust building, open communication, needful thinking, constructive conflict, etc.	Need of an effective facilitator; building trust among the individuals; facilitating dialogues among the individuals and the attitude to listen to the voice of concern and to contribute	Bridging organizations and simulating collaboration, building trust, providing information and encouraging development of a common vision
Knowledge consideration and management	Convergence of available narratives; several sources of knowledge and perspectives	Space for different views; understanding the sense of knowledge and ideas	Integrated understanding of social and environmental dimensions and changes, and respect for local knowledge
Tools and approaches			
Knowledge management	Different actors; workshop for joint knowledge production; card-sorting techniques; hexagon modelling	Output and input resource maps	Use and development of knowledge network and collective perspective maps; ICT tools
Capturing lessons		Framing/re-framing questions along with several field visits	Framing/re-framing questions along with several field visits
Interaction	Role playing; conferences; interactive influence model	Coordination platforms; farmers' participatory techniques	Public participation; collaborative learning; partnerships and research engagement; field visits, role-playing and policy simulation exercises
Simulation exercise	Agent-based social simulations and scenario analysis		Future scenarios and workshops
Validation and evaluation			
Process Evaluation	Individual observations; in-depth analysis of the transformation of participants' narrative	Interactive and participatory mapping	Self-assessment of the stakeholders
Outcome evaluation	Pre-post questionnaire; follow up interviews; evaluation of actors' experience		Monitoring and evaluation exercise; follow up on the knowledge gained and their plans in the future; environmental indicators measuring environment outcomes

Source: Harvey *et al.* (2013).

considered at the individual, system and network level. Gender and social analysis tools and mixed methods (quantitative and qualitative) of data collection are to be adopted. In addition, with the aid of modern tools like ICT and social network analysis, information among and across actors can be mined and architectures can be documented. Simulation exercises are also adopted with agent-based social simulation using futuristic scenarios. The third component is the validation and evaluation exercise, which comprises individual observation, interactive and participatory mapping and self-assessment of the stakeholder. Evaluation also involves evaluating the outcome using questionnaire surveys, interviews, along with monitoring, learning and evaluation exercises.

9.3 Sociological Perspectives

The study was conducted in semi-arid villages of India to bring out the sociological perspective of different groups and communities in the villages, and to distil their views and understand the following: (i) their perceptions on climate change; (ii) adaptation strategies and the associated constraints emerging at the technological, institutional and the socio-economical level of the farmers in the semi-arid tropics (SAT); and (iii) vulnerability and adaptation capacity based on their perceptions. For this study, purposive sampling was used to understand and identify perceptions of climate change and subsequent adaptation practices. The sample was stratified into large land-holding, medium and smallholder farmers, landless labourers and women. The rationale for this categorization was that each group had different levels of vulnerability and adaptive capacities on the basis of their resource and asset base. Focus group discussions (FGDs) and individual interviews were carried out with all categories of farmers, landless labourers and women using semi-structured questionnaires. Among the farming group, sufficient care was taken to interact separately with the first (older) and the second (younger) generation farmers in order to appreciate the differences and similarities in their perceptions and adaptation behaviour. The information gathered was triangulated by means of narratives, timelines and transect walks.

The analysis process, based on grounded theory, helped to tap the diverse perspectives of different groups and provide insights and develop an in-depth understanding of the issue by probing, clarifying and listening to stakeholders talk about the topic in their own words. Grounded theory is a well-established qualitative method for developing theories and conceptual frameworks in a way that is both inductive and deductive based on long-term fieldwork (Banerjee *et al*., 2013; Strauss and Barney, 1967). The process was iterative and attempts were made to keep clarifying the understanding of climate change among the respondents. It gave the freedom to the respondents to give their own interpretation of 'why' and 'how' the phenomenon was happening and 'what' they were doing based on their understanding. Key issues that emerged during the first round of data collection were incorporated into the analytical framework and further rounds of elicitation carried out to gain a deeper understanding of the subject. This process helped generate explanations regarding the impact and the adaptations, the role of institutions, technology, participation and collective action that were grounded in the context of climate change.

9.3.1 Do the farmers perceive climate change or variability?

The farmers perceive climate variability rather than climate change. Insert analysis of the data revealed that the effects of climate variability were most felt in the villages of Kanzara and Kinkheda in Maharashtra and Dokur in Andhra Pradesh. In the case of the two villages of Maharashtra, the farmers were increasingly beginning to feel the variability in climate over the past 5 years. The men, women and youth in Dokur had already been grappling with drought conditions for the last 18 years.

Farmers felt that there had been an increase in temperatures. The farmers also perceived and noted that there have been significant variations in the quantum and distribution of rainfall over the years. They believed that the rainfall was more intense, with fewer rainy days, and an extremely erratic distribution. It was claimed that, as compared to the 1970s when the number of rainfall days was 68 on average, it had currently reduced to an average of 45 days across the six villages.[1] Most of the respondents expressed concern about the off-season rains in the months of May, September and November that were becoming common in these parts of SAT, including in the villages of Aurepalle, Shirapur and Kalman. For the villagers, the fact that the months of June, July and August did not bring much rain both in quantum and distribution especially in the past 5–6 years indicated that climate had become more variable, rather than suggesting a consistent change.

9.3.2 Constraints to adaptation and vulnerability

The Capability Approach states that one of the factors that influences a person's or group's capabilities to adapt is the variation in social climate. Simply put, it means that the conversion of resources into function is influenced by social and institutional conditions. According to the approach, wealth or resources alone cannot act as a good indicator for judging an individual's capacity to adapt, rather it depends a lot on actual opportunities that a person has than their means (Sen, 1985; Sen, 1999; Nussbaum, 2000). The actual opportunities could be in the form of financial access, infrastructure facilities, education and learning, new technologies and practices, social relations, social capital and institutions. The adequate utilization of these depends to a large extent on the implementation will and efficiency of the local administration along with the conditioning of socio-cultural factors. The adaptive capacities of individuals or groups are influenced by these factors, which in turn constrain their capabilities. For instance, in the case of Dokur, the watershed programme that was started by the government in 1999 was seen as a positive step in water conservation. It was stopped in 2003 without any follow-up to revive it. The community attributed these failures in assistance to the lack of political will and prevalent corruption in the existing system, accentuating that there is a close relationship of risk to power. Groups that have less power and lack of access to resources are unable to determine public perceptions as to what constitutes risk. As a result, public policy responses are shaped by those who are powerful, and policies rarely reflect the needs of the less powerful and articulate sections (Tierney 1994). Similarly, the respondents in all the six villages and especially Shirapur complained that there was a dearth in the formal information sources and the guidance in terms of the types of seeds available, shorter duration varieties that were both drought resistant and yet profitable to grow. The respondents believed that, because of lack of government's initiatives in this regard, most people were ignorant and were continuing farming practices without being aware of what they were using. The respondents of Shirapur mentioned that the canal was an important source of irrigation for them; however, there were complaints of malpractices and mismanagement of the water distribution when it came to the village. The influence of the central authorities was most often conflicting with the needs of the locals, the water being diverted for industrial use. The issue of poor governance also emerged very strongly in Kanzara. The functioning of Gram Panchayat was considered to be of little service to them when it came to agricultural aid, especially during climatic shocks. This was a common observation in all the six Indian SAT villages. The respondents of Aurepalle and Shirapur pointed out, however, that the probable reason was the limited resource base that the Gram Panchayat had access to, which did not allow them to aid the farmers adequately. The labourers accused the Gram Panchayat of being inefficient regarding the implementation of the National Rural Employment Guarantee Scheme (MGNREGS). A similar concern was shared in Kinkheda regarding the implementation of one of the government schemes called The Pradhan Mantri Gram Rojgaar Yojana[2] (the Prime Minister's package for rural employment). The respondents felt that, even though the written formalities were complete, the scheme was yet to be put into practice. The medium group of farmers, especially in the villages of Kanzara, Shirapur and Aurepalle, felt that lopsided preferences of the government were an impediment in working towards preparing better to meet the challenge of the increasing climatic variability.

With regards to formal financial accessibility, other than in Aurepalle, none of the villages under the study had microfinance institutions or private bank establishments. In addition, the need for collateral and the negative attitude of the bank and co-operative officials towards smallholder farmers, labourers and women emerged as deterrents towards approaching these formal institutions for aid. This has led to a high dependence on private moneylenders in the villages and higher incidence of exploitation of smallholder farmers and landless labourers while obtaining credit. Though most of the women relied on their self-help groups (SHGs) for credit and savings, it was observed that the SHGs were running and being managed better in the Andhra Pradesh villages as compared to the Maharashtra villages. The Public Distribution System (PDS) no doubt had emerged as one of the most important institutions contributing to adaptive capacity in all the villages. The point of concern on certain occasions, however, was the quality of the food grains that were made available in the shop. Because there was limited or practically no choice on getting subsidized food, the community was accepting what was on offer. It was interesting to note, however, that in Kinkheda, the smallholder farmers and the labourers complained that the large-scale and medium farmers were getting the food grains at subsidized rates owing to the non-transparent manner in which the local government is distributing the Below Poverty Line (BPL) cards, issued by the central government.[3]

The willingness to act together and collectively towards management and access to resources plays a vital role in increasing or decreasing community or individual capabilities, which goes a long way in determining the resilience level of the community. A key constraint to adaptation was the lack of institutional arrangements for providing access to input and output markets. The reasons they cited were: (i) the lack of storage facilities in the villages and the need for finances (because most of the farmers were not very rich, they had to sell their produce immediately after harvest); and (ii) most importantly they did not have a co-operative of their own with the help of which they could negotiate better prices for themselves. The reason for the absence of the co-operative and storage facilities was attributed to the lack of collective will to create one. A noticeable practice of dairy farming was done in the majority of villages, viz. Aurepalle, Dokur and Kanzara. In Kanzara, where the respondents shared that as an alternative livelihood, it was, however, taking time to be accepted because of the requirement of high investments for the care and maintenance of the animals. In addition, the lack of disposition to work collectively had prevented the villagers from starting a milk co-operative. Similarly, though a co-operative had already started in Dokur, there were complaints of insincerity and lack of commitment from the community as the reasons for its failure in the past. In all the villages it was pointed out that the commonality regarding collective action was the coming together for a wedding, funeral or festival, which were part of the cultural and social norms to which a community is bound. In Kalman, Kanzara and Shirapur, however, some form of collective action existed among the farmers for the maintenance of the irrigation canals; otherwise it would hamper water supply to the fields. Barriers to collective action in the villages were cited as mutual distrust and the fear of exclusion and dominance of particular groups.

In all the six villages, the small farmers and labourers emerged as the most vulnerable group. In the case of Aurepalle, although becoming a farm servant was supposed to be a livelihood option for smallholder farmers, it appeared as one of the significant reasons for higher vulnerability among them as they got bound to the farmers who they were working for. In Kalman and Kinkheda, the lack of access to formal financial sources and inadequate information about the schemes and benefits available made the labourers and the smallholders dependent on middlemen and the moneylenders who most often than not were misleading them into farming and non-farming practices that were detrimental to their livelihoods, making them susceptible to future climatic shocks. In the case of Kanzara, there is a strong possibility that the medium farmers will be the next group to slip into the high-risk category because this group appears to depend purely on its own resource base without any external help from the local government structure. In Dokur, on the other hand, respondents were unanimous that dryland farmers were the most vulnerable group because their yields are continually affected unless there is adequate rain at the right time and the right amount. They did agree, however, that the labourers, though migrating, were also equally vulnerable because they depended a lot on the farm labour, which was dependent on the harvest that the farmers received.

9.3.3 Adaptive capacity and behaviour

In the villages of SAT India, though the farmers displayed significantly higher levels of adoption of new technologies,[4] some of the farmers spoken to in the study villages practised certain methods that were learnt as part of the farming practices over time (Box 9.1).

Farmers claimed that the rate of migration among the labourers had increased by 30–40% because of persistent droughts. The large land-holding farmers were still actively involved in agricultural activities though members of their families were migrating outside the village to look for work as a supporting livelihood strategy. Some of the existing dairy farmers had started the process of creating a milk co-operative by collecting and disseminating information among fellow members and looking forward to the organization having a representation of both men and women milk producers.[5] In the case of Kanzara the instances of

Box 9.1. Farming practices among SAT farmers in the study villages of India

Sowing: school teacher (Kalman)

When the rains come and it is time for sowing, everyone and all the farmers are in a rush to sow the seeds in the fields. My father always tells me to wait for a few days before I should sow. On asking the reason he told me that the incidence of birds and other creatures eating the seeds are higher during the first few days so it is always better to wait a few days and sow after the farmers have sown.

Fodder management: second-generation farmer (Kalman)

Sorghum, the moment it reaches 2–3 feet, the farmers start watering the crops and as a result of which the stalks become thick and heavy and are not conducive for fodder. We do not buy fodder, we use the stalks of the sorghum to feed our cattle and if the stalks are too thick then the animals don’t eat them. But if they are small and thin then they eat them. So we keep the stalks thin and small so we use less water. Also if the stalks are big in size and if some uncalled for rains come then the pods tend to fall off easily, which doesn’t happen if the plant is short and thin in size.

Nutrient management: second-generation farmer (Kanzara)

I don’t burn my fields after the harvesting of wheat. The reason why I don’t burn my land but till it instead, even though it takes more effort, is because the fertility of the soil gets compromised if burnt. I let the natural heat burn the remains of the wheat post harvesting during the summers as the stubs of the wheat plant is rich in silicon which is good for the soil.

in-migration were more than the instances of out-migration. The construction of the airport near Aurepalle and the presence of industries like the sugar factory and the Maharashtra Industrial Development Corporation (MIDC) in Shirapur had led to traditional coping strategies being integrated through diversification of livelihood occupations. There was temporary migration taking place to the nearby airport village, nearby towns and the cities of Hyderabad, Solapur, Pune and Mumbai. This was especially true in the case of the poor or smallholder farmers and the youth who did not mind leaving their farms to pursue other sources of income even during normal years. Often they joined existing people who had earlier left their villages over a given period of time. In the case of Shirapur, some of the respondents had government jobs with fixed salaries. Both the villages of Kanzara and Shirapur displayed the trend of starting small businesses through petty shops and accessories or roadside hotels either in the village itself or on the outskirts. Like in Shirapur, in Kalman the rate of migration was more to cities like Pune and Mumbai predominantly among the youth. The reasons were access to transport and better wages being paid outside the village as compared to within the village for the labour work.[6] The migrations were mostly short term especially in the event of a loss suffered due to a climatic shock (drought).

In the Maharashtra villages, it was seen that the farmers in Kanzara and Kinkheda had taken to adoption of new, high-yielding varieties and short-duration crops. The diversification had taken place mainly towards soybean and vegetable growing such as coriander, spinach and onions because their growing periods were relatively shorter as compared to food crops. The short growing period allowed the farmers to use the fields to grow more crops both in the rabi and kharif season, while rainy and post-rainy soybeans were fetching a high price in the market. An interesting observation was that some of the farmers had used the delayed and fewer rains to their advantage by intensifying cultivation of vegetables like brinjal (aubergine) and cucumber, which grew well under the mentioned conditions. Some of the farmers continued to grow cotton in spite of water shortage because they believed that it was still the most commercially viable choice at their disposal. In Shirapur, it was claimed that the presence of irrigation had reduced the impacts of climate change on agriculture, though efficiency of water usage needed to be improved. The majority of farmers had diversified into growing sugarcane for the last 8–10 years. Among the food crops, pigeonpea and sorghum were grown for subsistence. There were about 3–4% of the farming community who had diversified into horticultural produce, although the production of grapes had drastically reduced because it was found to be highly susceptible to the erratic climatic conditions. In Kalman, some of the medium-scale farmers were exploring possibilities of poultry farming. Many farmers were diversifying into growing drumsticks (moringa), tomatoes and onions because they were not only less water consuming but also gave good returns in the market. The commonalities in the case of Aurepalle and Dokur were in the shift that the farmers had made to short-duration paddy seeds[7] since 1995. It was interesting to note though that, in Aurepalle, despite this shift along with sunflower and maize, they were continuing to grow groundnut and Bt cotton. The government provided subsidies on drip irrigation system to grow groundnut and encouraged the farmers to get back into groundnut growing even though it was water intensive. Like in Kanzara, since Bt cotton was perceived to be the most commercially viable crop, most of them had shifted to allocating certain parts of their farms to growing cotton.

A common observation across all the six villages, irrespective of the differences in soils, was that most of the farmers were experimenting with crop choice using short-duration pigeonpea and sorghum. It should be noted, however, that most of the farmers interviewed acknowledged that, in addition to climatic conditions, the reasons for diversifying were the commercial values received for the crops in the market. Particularly worth mentioning were the strong sense of awareness among the farmers regarding the conservation of water and the need for water harvesting to raise the depleting water tables. The villagers in Dokur felt that the revival of the watershed project, which was suspended in 2003, would go a long way to solving water shortage problems, at least with respect to farming. The suggestion of pricing of water to ensure its optimal use in Shirapur was evidence enough of the consciousness for the requirement of the judicious usage of water.

The growing significance of the role of institutions in enhancing the adaptive capacity to climate change was evident in all six villages. It was observed that the government programmes in the Andhra Pradesh villages Aurepalle and Dokur were running more efficiently than they were in the four Maharashtra villages. Most of them were quite useful to most members of the village, particularly to the labourers and smallholders as compared to the ones in Akola and Solapur villages. The government had appointed two people from each village as Adarsh Raitu (Ideal Farmers) for Rs 1000/- (US$20) per month to serve as government agents in the village to inform the community on the subsidies and schemes regarding agriculture. It was observed that although the labourers and the small farmers completely relied on the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) and the Public Distribution System (PDS), the medium landholding farmers were using and benefiting from the same. It can also be inferred that the community themselves, irrespective of socio-economic status, were dependent on government programmes for long-term adaptation strategy. Though there were governance and accountability issues, particularly in the Akola villages of Maharashtra, the smallholder farmers were nevertheless making use of the subsidies given by the government to increase their resource base by digging wells and using fertilizers for their fields, although they were also preparing to migrate out of the village if the climatic situations got worse.

It was for reasons such as these that the farmers did not mind depending on the input supplier for advice on the varieties available and if the variety was high yielding, short duration, as well as drought resistant, it worked in favour of the farmers. In the Akola villages, the second-generation farmers were also quite forthcoming when it came to asking for advice from the Krishi Vigyan Kendra (KVKs), which are the agricultural extension service providers designated by the Government of India. There was no mention, however, of seeking any form of assistance from the KVKs in the remaining four villages. For information, the second-generation farmers in Kanzara were forthcoming about approaching the KVKs, unlike the first-generation farmers, though the first choice for counsel on agricultural inputs and crop variety was ICRISAT. An interesting observation made in the six villages was that, in spite of the uncertainty of rainfall and the potential threat of climate variability increasing in the coming years, the first-generation farming community still preferred agriculture to any other form of livelihood. Though crop insurance was not very popular among the farmers because of the lack of understanding of the implementation process, it was acknowledged by the respondents that it was a good mechanism against the variability of climate. The farmers who had taken crop insurance in Maharashtra villages in the last 6 years had done so as a possible safety against the increasingly erratic and uncertain weather conditions.

Women across the study villages were totally dependent on the SHGs not only for financial assistance but as a platform to mediate access to technology and credit, especially in the Mahabubnagar villages; in the case of the Shirapur and Kalman villages it was more for acquiring credit for non-farming activities like meeting household expenses and starting petty business; whereas in Kanzara and Kinkheda the credit was used for farming activities. This reliance on SHGs was in spite of the fact that they were not desired in Dokur and Aurepalle villages, the SHGs were successful in leveraging collective action amongst women. Dairy farming was emerging as a potential source of livelihood in the study villages; in the case

Table 9.2. Recovery period of various groups with relation to climate shock/bad year.

	Time span to recover (years)[a]			
Category of respondents	Dokur	Kanzara	Aurepalle	Shirapur
Big farmer	2–3	1–2	1–2	1–2
Medium farmer	2–3	2–3	2–3	3–4
Small farmer	3–4	4–5	2–3	3–4
Labourers	3–4	3–4	2–3	3–4
Women	Dependent on household	Dependent on household	Dependent on household	Dependent on household

[a]This is assuming only if the following year is a normal year or a favourable year. Source: Farmer FGDs in Kanzara and Dokur, 2009.

of Shirapur, a particular entrepreneur in the village who had established a milk dairy for collective marketing was offering loans to the small farmers that were paid back through delivery of milk.

Co-operatives in the SAT villages played a vital role in helping the farming communities to get access to financial assistance. The medium-scale farmers, especially, depended on the co-operatives for financial aid as compared to the women who relied completely on their SHGs for any financial assistance, be it for farming or non-farming purposes. FGDs revealed that in all six villages social capital played an important role when it came to the improved adaptive capacity of a group or individual because: (i) it was a source of finding livelihoods on migration to the cities and other places outside the villages; and (ii) when there was a bad year or a climatic shock, the first reaction had always been to approach their most trusted people who could be in the form of friends, relatives, parents and even local moneylenders. When asked about the recovery period from a climatic shock, the respondents were of the opinion that the average time frame was at least 2 years for a farming community and 3–4 years for a non-farming community, assuming that the year following the climatic shock was a favourable one (Table 9.2).

Drawing from the studies carried out in the six different villages, it can be synthesized that: (i) adaptation measures were adopted by the villages and enabled by state agencies, (ii) main constraints faced by farmers were not just access to financial resources but also social and institutional resources; and (iii) the opportunities for optimizing adaptation were context specific. This synthesis provides the information base from which key conclusions are drawn and policy directives recommended.

9.4 Summary and Conclusion

The empirical study addresses the importance of sociological underpinnings in understanding the role of climate variability in the livelihoods of agriculture-dependent communities in the region. Sociological analysis is important to understand the nuances of the interlinks between agriculture and society. Studies on the perceptions of the farmers on climate trends, coping mechanisms, adaptation options, etc., enable an understanding of the various perspectives of climate vulnerability. It is also important to know the aspirations of the different strata in the community towards climate-related emergencies. Through the case study, this chapter describes in length the perceptions, adaptive capacity and behaviour towards climate change, and identified constraints to adaptation and vulnerability to climate change.

Notes

1 The perception of the farmers seemed quite accurate because this information was confirmed

by the first-generation ICRISAT resident investigators working in these villages. In addition, the climatic data obtained from the district level concurred with the description of the years of the extreme events by the farmers.

[2] The programme with an objective to provide additional employment wages in rural areas in India. This targets the nature, creation of community assets with special emphasis on women, schedule casts, scheduled tribes and parents of children withdrawn from hazardous occupation.

[3] It was claimed that the local government had been distributing the BPL cards to the non BPL group, as a result of which they were benefiting. The BPL members, on the other hand, were being forced to buy the grains at a regular price without any subsidies.

[4] New technologies are defined as those technologies that have been introduced to them at some point after the 1950s in India. They include tractors, fertilizers and pesticides and the more recent hybrid and short-duration seeds.

[5] There is a milk co-operative that is about 5 km away from the village. The milk is sold to the nearby hotels at Rs12/- to Rs15/- per litre, depending on the fat content. The quality of milk is measured on the basis of its fat content. The villagers sell the milk directly, even to those traders who come from the cities.

[6] In the village it is Rs70/- per day but outside the village in the nearby areas or villages it is Rs80/- on a daily basis for work like road construction work, laying bricks and even maintenance and expanding of the canal work.

[7] Unlike the traditional paddy seeds that took almost 6 months to get ready for harvesting, these seeds would mature and be ready for harvesting in less than 4 months.

References

Adger, W.N. (2000) Social and ecological resilience: are they related? *Progress in Human Geography* 24(3), 347–364.

Adger, W.N. (2003) Social capital, collective action, and adaptation to climate change. *Economic Geography* 79(4), 387–404.

Agrawal, A. (2008) The role of local institutions in adaptation to climate change. *International Forestry Resources and Institutions Program Working Paper* 081–3.

Banerjee, R., Bantilan, M.C.S. and Singh, N.P. (2013) Exploring the relationship between local institutions and adaptation to climate variablity. *Natural Hazards* 65, 1443-1464

Bantilan, M.C.S., Babu, P.A., Anupama, K.V., Deepthi, H. and Padmaja, R. (2006) *Dynamics, Challenges and Priorities of Dryland Agriculture in Asia and Sub-Saharan Africa*. Research Bulletin No. 20. Technical Report. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India.

Bohle, H.G., Downing, T.E. and Watts, M.J. (1994) Climate change and social vulnerability: toward a sociology and geography of food insecurity. *Global Environmental Change* 4(1), 37–48.

Harvey, B., Ensor, J., Garside, B., Woodend, J., Naess, L.O. and Carlile, L. (2013) *Social Learning in Practice: a Review of Lessons, Impacts and Tools for Climate Change Adaptation*. Working paper No. 38. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Hassan, R. and Nhemachena, C. (2008) Determinants of climate adaptation strategies of African farmers: multinomial choice analysis. *African Journal of Agricultural and Resource Economics* 2, 83–104.

Nussbaum, M. (2000) *Women and Human Development.* Cambridge University Press, Cambridge, UK.

Semenza, J.C., Hall, D.E., Wilson, D.J., Bontempo, B.D., Sailor, D.J. and George, I.A. (2008) Public perception of climate change voluntary mitigation and barriers to behaviour change. *American Journal of Preventive Medicine* 35, 479–487.

Sen, A. (1985) *Commodities and Capabilities.* North Holland, Amsterdam.

Sen, A. (1999) *Development as Freedom*. Anchor Books, New York.

Strauss, A.L. and Barney, G.G. (1967) *Discovery of Grounded Theory: Strategies for Qualitative Research.* Hawthorn, New York.

Tierney, K.J. (1994) Sociology's unique contribution to the study of risk. *Paper presented at the 13th World Congress of Sociology,* Bielefeld, Germany.

10 Policy Options Towards Climate Resilience: Agent-based Assessment of Farm Households in West Africa

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Abstract

This chapter will present the impacts of farm-level adaptation strategies on farm household income and food security under the changing climate in Northern region of Ghana using a bio-economic modelling approach. The modeling approach captures the heterogeneity of important resources of farm households such as access to credits, irrigation and non-farm income sources under the context of climatic change.

10.1 Introduction

While reducing poverty and ensuring food security is a major priority of many governments of developing countries, the complex and ever-changing impacts of climate variability coupled with dependencies on weather-sensitive agriculture has become a major threat for poverty and food insecurity reduction efforts. According to the Food and Agriculture Organization (FAO, 2008), climate change will have a far-reaching consequence for agriculture that will inevitably affect the poor. In this regard, Ghana's economy is highly exposed to the adverse effects of climate variability as agriculture forms the basis of the economy, contributing roughly 30% to GDP and providing livelihood for 60% of the population (Wossen *et al*., 2014).

In addition to dependencies on climate-sensitive livelihoods, farm households in Ghana are sensitive to the impacts of climate variability owing to the lack of adaptive capacity resulting from pervasive poverty. Despite the impressive progress shown in Ghana, the Northern part of the country in general and the Upper East Region (UER) in particular remained poor with a poverty rate of 73% in 2005/2006. As such, with climate change and variability one can expect poverty and food insecurity to be exacerbated. Differences in vulnerability might also be caused by differences in the extent of exposure to climate variability, sensitivity of households to the impacts of variability and the level of the household's adaptive capacity (Adger *et al*., 2005). In line with this, Busby *et al*. (2013) analysed hot spots of climate variability in Africa and

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found considerable variation in vulnerability to climate variability and change between and within countries. In particular Ghana was found to be highly vulnerable to climate variability, with the northern part being extremely vulnerable to the impacts of variability.

In Ghana, the adverse effects of climate change are already evident; natural disasters are more frequent and more devastating and poor people have become more vulnerable (Yilma, 2005). In Northern Ghana where livelihood choices are limited, rainfall variability has become a real threat to food security and poverty by decreasing crop productions. In the UER of Northern Ghana, agricultural production under semi-arid conditions remains the main source of income for most rural communities. Besides that, UER is among the poorest regions in Ghana with poverty incidence rate of above 70% compared to the national poverty incidence rate of 28% (Yilma, 2005; Gyasi *et al*., 2006; GLSS, 2008). Food insecurity is another critical and worrying issue because agriculture is predominantly rainfed, which leads to high uncertainties and low levels of production especially when there is no adequate rainfall during the rainy season. Therefore, adaptation of the agricultural sector to climate variability is imperative to protect the livelihoods of the poor and to ensure food security in the area.

So far, there are very few empirical studies that examine the potential effects of climate variability in the context of small-scale and semi-subsistence agriculture in northern Ghana. Previous works have also been limited on assessing the effects of climate variability on agricultural productivity in general and its implications on poverty and food security in particular. As indicated by Hertel *et al*. (2010), however, productivity changes alone are a flawed indicator of the full adversity of climate variability because earnings from higher food prices can also be an important driver of poverty. The overall effect of climate variability on poverty and food security therefore depends on the magnitude of productivity shocks, the rate and speed of productivity induced market price changes, the market position of households (net buyer versus net seller) and the extent of market integration of farm households (Hertel *et al*., 2010; Wossen and Berger, 2015). Analysing these effects is crucial in order to design appropriate targeted policy interventions that can offset the potential adverse effects of climate variability considering heterogeneity of households' policy responsiveness.

Moreover, past attempts to estimate the impact of climate change on food production, poverty and food security were mainly concerned with the global, country and regional level (Nelson *et al*., 2007). These studies have shown the different mechanisms in which climate change may affect food production, poverty and food security in a more generalized way using computable general equilibrium (CGE) and econometric models. To the authors' knowledge, attempts to estimate the impact of climate change at agent level are almost non-existent. This paper therefore examines the effects of climate variability using an agent-based model (ABM). A key motivation for using an ABM in climate change studies for agricultural-household policy analysis for cases in which households make production, consumption and labour supply decisions is its ability to account for their interaction with the environment at any spatial and temporal scale (Berger, 2001; Yilma, 2005).

In addition, in an integrated ABM, production, investment and market risks are endogenous, making prediction of the impact of climate change more accurate (Berger, 2001; Berger and Troost, 2013). The approach employed in this study captures the non-separability of production and consumption decisions. Assumption of separability in production and consumption implies that a household's decision regarding production is not affected by consumption preference (Schreinemachers and Berger, 2011). However, the assumption of separability in consumption and production is misleading because climate-induced changes in production requires farm households to adapt their consumption behaviour by shifting towards goods that are less sensitive to climate variability, which clearly affects welfare level. Moreover, the assumption of separability of production and consumption decisions is a flawed concept for analysing the effects of climate variability because rural households in many developing countries are both producers and consumers with prevalent market imperfections (Mideksa, 2010). Previous studies on climate variability, however, did not take into account non-separability of production and consumption decisions of farm households, which might be misleading in a sub-Saharan Africa (SSA) context.

This study therefore applies a novel agent-based modelling approach to examine the impacts of climate variability on food security and poverty. Specifically, using data from the 2005/06 Ghana Living Standard Survey (GLSS 5) and the CGIAR Challenge Program on Water and Food (CPWF), along with detailed local level price and rainfall data, this chapter quantifies climate variability effects at the household level. In addition, the chapter investigates to what extent and for whom variability matters with regards to food security, as well as whether the effects of variability are distributed uniformly. Finally, this chapter assesses how policy interventions, especially those related to the promotion of credit and off-farm employment, affect the distribution of food security under climate and price variability. The remainder of this chapter is organized as follows. Following this basic introduction, the next section opens with a basic conceptual framework on the link between variability and food security and an introduction to the roles possible adaptation options may play. Following the conceptual framework, the main strengths of ABM for climate impact assessment are discussed. The final section discusses our findings and the relevance of ABM for climate impact assessments, and concludes with a list of open questions and an outlook on next research steps.

10.2 Conceptual Framework

We identified different pathways through which climate variability may affect household food security in Ghana. In particular, we considered impacts on household food security and poverty. Other pathways, such as through non-priced goods and damages to infrastructures, are not captured in this chapter. After establishing the pathways as well as the magnitudes of climate variability effects on household food security and poverty, the chapter then proceeds in examining the effectiveness of adaptation options, both autonomous and planned ones, including the distributional effects of such interventions. Food security is a complex issue that requires an all-encompassing measurement and definition. The most widely used and accepted definition of food security is based on the 1996 World Food Summit. Accordingly, food security exists 'when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life' (FAO, 1996). The above definition encompasses the availability, access, stability and utilization pillars of food security. These pillars of food security are naturally linked and can be viewed at the global, national, household or individual level. Achieving food security at the national level is necessary but not sufficient, to ensure household food security

The conceptual framework in Fig. 10.1 shows the link between variability, possible adaptation options and food security outcomes. Climate variability manifested by changes in rainfall amount, intensity and timing, as well as through changes in temperature, affects food security outcomes through many pathways. Depending on the severity of climate variability and the adaptation options undertaken by households, climate variability effects will be manifested in terms of changes in crop yields. Changes in crop yield then directly affect the availability component of food security. Impacts on crop yield could also be reduced, however, through appropriate adaptation strategies. The extent of rainfall variability, for example, shapes the kind of adaptation strategies adopted by households. With extreme variability, households may make use of off-farm employment options or adopt risk-mitigating strategies, such as soil and water conservation practices.

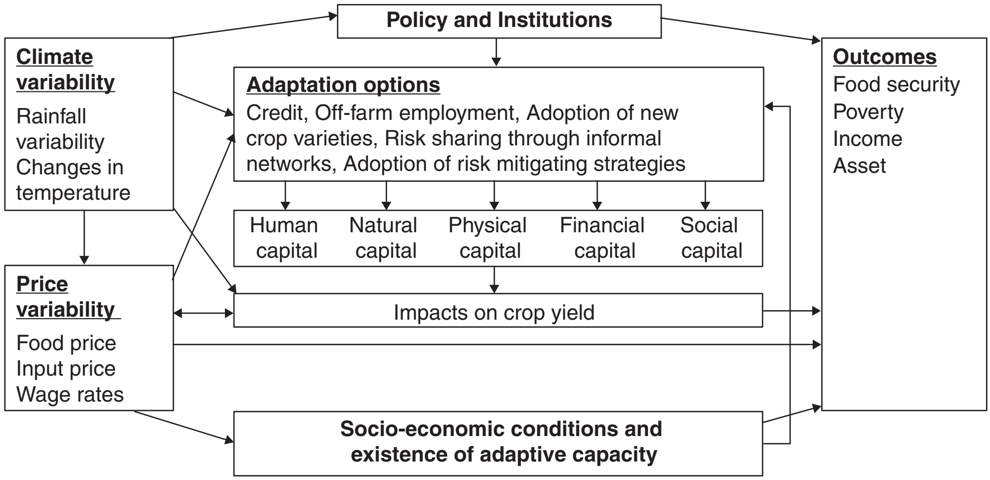

Fig. 10.1. Conceptual framework. Based on Chijioke *et al.* (2011).

The type of adaptation strategies adopted by farm households is also affected by the adaptive capacity of those households, which is in turn affected by the household's resource endowment. Differences in access to the different components of capital and resource endowments are important in shaping not only the type of adaptation options available to households but also the intensity and effectiveness of such adaptation options. As such, the use of ABM is crucial in capturing differences in adaptive capacity among households, as they are different in access and possession of the different components of social capital (natural, physical, social, etc.).

The other pathway through which climate variability affects food security is through changes in relative prices. Because high climate variability affects the supply of food products, it is easy to see that it will have an effect on food security through what is commonly called climate-induced price variability. The problem of price variability can, however, be persistent even without climate variability owing to changes in domestic policies, exchange rates, trade policies and other factors. As a result, while examining outcomes such as food security, it will be important to capture both climate-induced and non-climate-induced price variability. Price variability on output prices, input prices and wages affects food security in many ways. First, changes in output prices affects crop choice and production decisions of farm-households, and hence productivity of crops and food security. Second, changes in the relative price of inputs such as fertilizer and seed affect input-use decisions, and hence crop productivity and food security. And finally, changes in wage rates affect the household's ability to access food. Even though climate variability is widely expected to affect productivity and food security adversely, the impacts of price variability are not clear. The effects of such price variability therefore depend on the magnitude of productivity shocks, the rate and speed of productivity induced market price changes, the market position of households (net buyer versus net seller) and the extent of market integration of farm households.

Prudent institutions and the policy environment are also important in reducing the impact of climate and price variability and hence improving food security. On one hand, the extent of variability affects the type of policy directions. On the other hand, institutional capacity and policy environment are crucial in reducing the impact of variability. In addition, institutional capacity and the policy environment also affect the type and extent of adaptation strategies undertaken by households. For example, the strength and ability of institutions determines whether households can adopt new crop varieties and access short-term credit or off-farm employment options. Policy and institutional set-ups are also important in reducing climate variability impacts on food security, for example, through food aid and other relief programmes.

The other very important aspect of adaptation options in light of climate variability is reliance on informal social networks in providing insurance against shocks. It has been documented that some forms of informal social links and organizations have an explicit insurance component against shocks. Furthermore, some aspects of social capital and extended kinship networks help to insure consumption against shocks through moral obligation, sharing and redistribution of resources (Di Falco and Bulte, 2013). Given that formal risk-sharing mechanisms are largely limited in many developing countries, including Ghana, we expect social capital to be helpful in maintaining consumption in the face of rainfall shocks. As such capturing the roles of informal social networks and social capital on the household's ability to insure food security under variability will be very important.

In addition, social capital and informal social links are important in enhancing adoption of risk mitigating land management strategies in order to reduce the impacts of climate variability. An individual's access to social capital impacts adoption of risk-mitigating land management practices by reducing some of the prevailing market inefficiencies and supply-side constraints of adoption. Examples of market imperfections that impede adoption of risk-mitigating strategies that may be reduced through social capital include missing markets for risk, credit, labour and information (Shiferaw *et al.*, 2009; Jack, 2011). In particular, in the absence of well-functioning formal labour, credit and information markets, social capital enhances adoption by helping individual adopters to overcome their labour and cash constraints (Krishna, 2001) and by facilitating the flow of information by reducing asymmetric information and transaction costs (Abdulai *et al.*, 2008).

10.3 Reliability of ABM for Assessing Climate Change Impacts

A wide range of methods, including simple cost–benefit analysis, empirical field survey methods, econometric (Ricardian) models, statistical models, partial and general equilibrium models, ABMs and process-based crop simulation models have been applied in examining the impacts of climate variability and change, as well the effectiveness of adaptation options (Lippert *et al.*, 2009; Arndt *et al.*, 2011; Berger and Troost, 2014; Di Falco and Veronesi, 2014; Nelson *et al.*, 2014; Wossen *et al.*, 2014). In analysing the effects of climate variability, there is no doubt, however, that integrated models are needed. All integrated models have so far agreed on the expected impacts of climate variability and change, but they differ significantly on the magnitude of such effects (Nelson *et al.*, 2014). These discrepancies are also partly attributed to the definition of impacts. Some models, for example Ricardian analysis of climate variability, take into account adaptation in the calculation of impacts, whereas other models, such as crop growth models, do not.

While partial and general equilibrium models are designed to capture effects at global, national or regional level, ABM and Ricardian approaches are well suited to undertake impact assessment at the farm and household level. Because the focus of this chapter is to model climate variability effects at the household level, emphasis is placed on the use of ABM. It is worth considering partial equilibrium models, however, when analysing effects at the sectoral level (such as the agricultural sector). Similarly, general equilibrium models are suited for analysis of economy-wide effects of climate variability. Both partial and general equilibrium models of climate variability are not household-level models because they provide aggregate costs of climate change and variability. These models are, however, able to capture the different pathways through which climate variability may affect the economy. These include productivity shocks, output and factor price changes, as well as effects through wage rates.

Crop growth models are process-based approaches to understand the impacts of climate variability and change on crop production systems (Lobell *et al.*, 2008). Such procedures have been applied in a wide range of crops and countries (Lobell *et al.*, 2008; Biggs *et al.*, 2013; Nelson *et al.*, 2014). Different varieties of crop growth simulation models have been applied for assessing the impacts of climate change. Crop growth models are used to estimate the impacts of climate variability on crop yields, considering other management factors. The advantage of using crop growth models for capturing climate-induced production shocks is that they are process-based applications. For example, DSSAT (Decision Support System for Agrotechnology Transfer) captures the effects of climate variables on crop yield on a daily basis, whereas the model CROPWAT was parameterized to capture effects on a monthly basis (Schreinemachers and Berger, 2011). In addition, such models allow for the specification of other management techniques, such as the use of labour and fertilizer, along with climate variables for capturing production shocks.

In addition to process-based models of crop growth simulations, other statistical and econometric approaches have been extensively used for the assessment of climate impacts. Among these, the Ricardian approach pioneered by Mendelsohn *et al.* (1994) is the most widely used. The Ricardian method estimates the impacts of climate change by regressing land values or farm revenue on a set of climate variables and other exogenous controls[1] (Mendelsohn *et al.*, 1994; Lippert *et al.*, 2009; Di Falco, 2014). The major advantage of this methodology over pure process-based crop growth models is its ability to model adaptation while estimating climate variability effects. The use of Ricardian analysis has some limitations, however, for the analysis of climate variability-induced welfare changes owing to the following reasons.

The use of cross-section data for the analysis of impact assessment creates bias due to potential omitted variables. Although attempts have been made to reduce potential omitted variable impacts through the use of fixed-effect models, the majority of the studies conducted so far have been based on cross-section data. Furthermore, the model assumes that climate change/variability effects are reflected in land rental values (Hertel *et al.*, 2010). This assumption may become bold, since formal markets for land are missing or under-developed in many developing countries. In addition, the model relies on past observation assuming unchanged production structure and farmer behaviour. This lack of a process-based underpinning makes longer-term predictions with these models questionable (Berger and Troost, 2013). As such the model neither takes into account adjustment costs to the new climate nor impacts on household food security because it does not consider non-separability in production and consumption.

Modelling food security and poverty under climate variability needs to take into account a large number of complex and interrelated factors that can only be captured through integrated household models (Berger and Troost, 2013). As such, a model capable of capturing the complex relationships between the biophysical and socio-economic processes, while also considering complexity and heterogeneity, will be crucial in examining climate and price variability effects in the context of smallholders in SSA. One such methodology is the use of ABM, which models decision-making processes while considering high degrees of heterogeneity, nonlinearity, interaction and feedbacks, and emergence (Berger, 2001). In this regard, we implemented an agent-based model called Mathematical Programming Based Multi-Agent System (MPMAS) that captures farm-level impacts of climate variability while capturing a wide range of adaptation options. In particular, MPMAS is an important tool for the farm-level assessment of climate variability impacts on food security and poverty by considering important micro-level constraints such as environmental externalities, limited adaptive capacity and behavioural barriers (Berger and Troost, 2014).

MPMAS is able to represent uncertainty in production and consumption decision-making processes, is flexible enough for impact assessment, captures causes and outcomes of adaptation processes due to its recursive nature, and assesses tradeoffs and synergies between food production, consumption (and hence food security) and environmental impacts resulting from the use of adaptation options (Fig. 10.2). Furthermore, the model is very strong in the quantification of consequences from variations across different households in terms of resource and wealth dynamics, adaptive capacity, production and consumption preference, knowledge and learning ability. Because MPMAS captures farm-level costs explicitly, adaptation to climate variability occurs endogenously. Furthermore, by incorporating interactions and feedbacks between the socio-economic and biophysical processes, MPMAS is able to capture the biophysical (climate variability) impacts on socio-economic process (food security, poverty, etc.).

In addition, MPMAS treats agents as autonomous decision makers and allows a great deal of flexibility in how decision-making processes are represented (Berger and Troost, 2014). In addition, by explicitly capturing agent-to-agent and agent-to-environment interactions, MPMAS becomes crucial for modelling technologies for reducing climate variability impacts. Agent-to-agent interactions are related to interactions between agents for sharing resources and information for technology adoption. This involves an agent receiving information about (being exposed to) new agricultural technologies. For the case of Ghana, the crucial effect of agent-to-agent interactions was captured by using a network threshold approach. In addition, MPMAS was parameterized using econometric techniques (based on adoption thresholds as estimated based on the time lag and adoption probabilities) in order to determine agent-to-agent interactions for the adoption of adaptation strategies.

Because adoption of risk-reducing adaptation strategies against the adverse impacts of climate variability requires agent-to-agent interactions in which heterogeneity between agents and social relationships play a significant role, the use of MPMAS will be appropriate (Berger and Troost, 2014). Another aspect of complexity that is captured

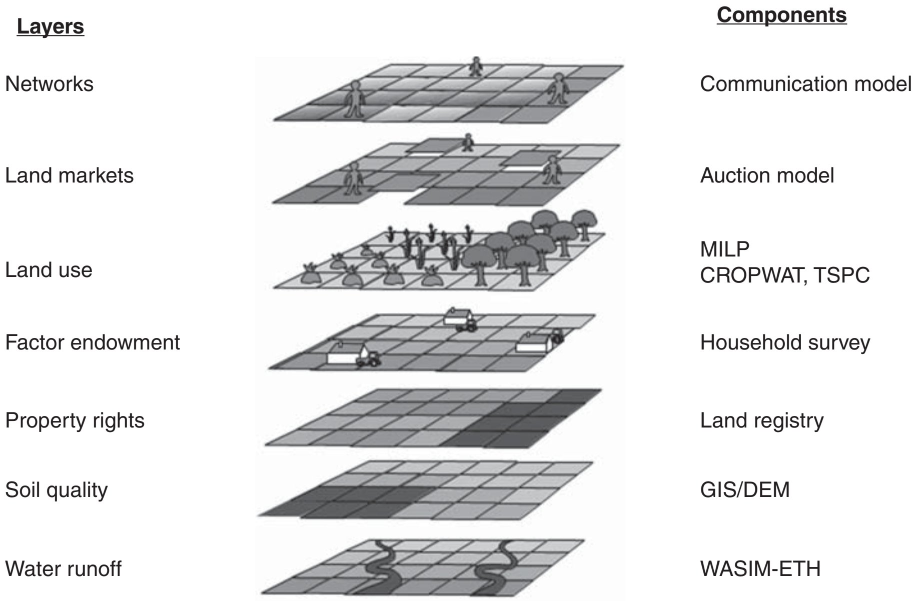

Fig. 10.2. Components of MPMAS. Source: Berger *et al.*, 2007. MILP = mixed-integer linear programming, TSPC = tropical soil productivity calculator, GIS = geographic information system, DEM = digital elevation model, WASIM-ETH = Water balance Simulation Model ETH

in ABM is agent-to-environment interactions. As implemented now, agents influence the environment through their land use and input decisions, while the environment influences agents by returning a level of crop yield, which is a function of input decisions and environmental processes such as weather, water flows and soil nutrients (Schreinemachers and Berger, 2011). In addition, MPMAS is able to mix simple heuristic and optimization techniques in capturing agent-to-agent interaction. By doing so, it exploits the advantages of optimization models while reducing reliance on a rational decision maker with perfect foresight as opposed to bounded rational agents (Schreinemachers and Berger, 2011).

In particular, in this ABM model, household decision making is modelled using mathematical programming (MP) techniques (Fig. 10.3). The MP approach assumed each household to maximize the expected utility (which consists of cash income from sales (crop and livestock products) and off-farm labour, in-kind income from self-consumption of crop and livestock products, and the annuity of future expected income from investments) under constraints such as different types of land, labour, capital, irrigation water, consumption requirements, etc. Owing to the presence of market imperfections in the UER, cash income and in-kind home consumption objectives are included separately in the model objective function, i.e. the production and consumption decisions of households are non-separable and must both be taken into account when optimizing land use decisions (Holden and Shiferaw, 2004; Woelcke, 2006; Schreinemachers and Berger, 2011; Nedumaran *et al*., 2014). For each year in the simulation, investment, production and consumption decisions of households are captured. The matrices are household-specific and differ in terms of internal matrix coefficients (e.g. yields and consumption function coefficients), objective function (e.g. prices), right-hand-side values (e.g. resource endowments, assets and liquid means), and in the number of included constraints. Investment and production decisions are based on expected yields and prices.

The data used to develop our ABM comes from the household survey conducted

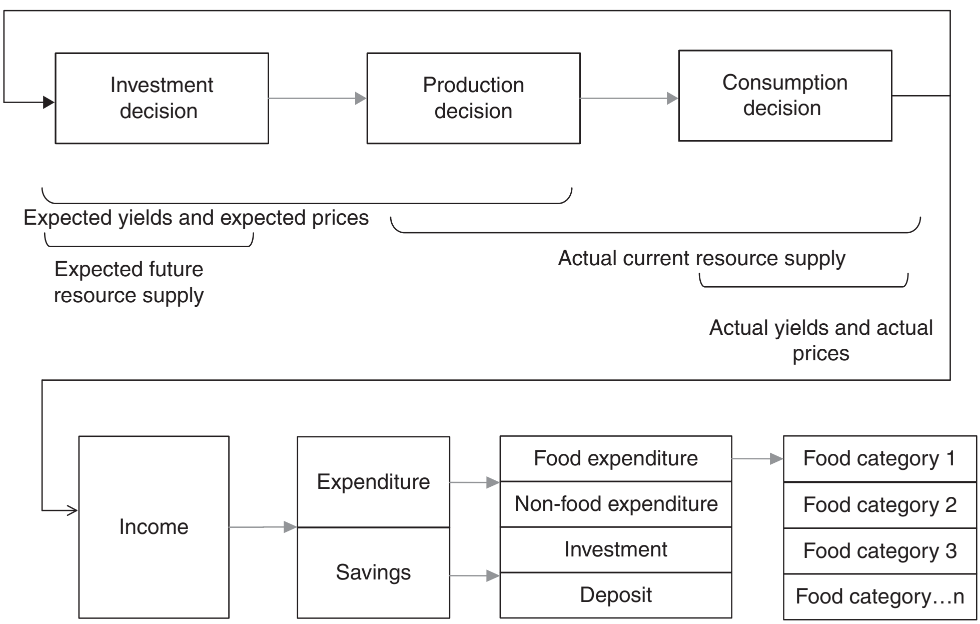

Fig. 10.3. Decision-making process in MPMAS. Based on Wossen and Berger, 2015.

in 2006–2007 as part of the CGIAR challenge programme on water and food and from the 2005/06 Ghana Living Standard Survey (GLSS 5). The GLSS 5[2] data set, which is a nationally representative survey of 8687 households, is used to estimate household consumption patterns, while the biophysical model is parameterized through daily precipitation and temperature data.[3]

10.3.1 Simulating crop yields using the CROPWAT model

The crop-specific effect of climate variability on yield is captured through the crop-growth model component of MPMAS based on the FAO 56 approach (Smith, 1992; Clarke *et al.*, 1998). The model is parameterized through daily precipitation and temperature data. The crop water requirement (CWR) for crop i in month m is the product of a crop coefficient (Kc), the potential evapotranspiration ($ET0$), and the planted area (A):

$$CWR_{i,m} = Kc_{i,m} * ET0_m * A_{i,m} \tag{10.1}$$

The CWR is met through rainfall and complemented via irrigation (IRR). In the model total rainfall is converted into effective rainfall (ERF) using the USDA soil conservation service formula to capture the share of rainfall actually available to the crop, depending on its growth stage. Deficit irrigation water (DIRR) was then calculated as the difference between the crop water requirements and the effective water supply, which includes effective rainfall and irrigation:

$$DIRR_{i,m} = CWR_{i,m} - ERF_{i,m} - IRR_{i,m} \tag{10.2}$$

The crop yield reduction factor (CYF), which captures the effects of climate variability on crop yield for each crop, is then computed as:

$$CYF_c = 1 - Ky_c(1 - \frac{ETA_c}{ETC_c}) \tag{10.3}$$

which captures the yield response factor of each crop, captures crop specific actual evapotranspiration and refers to the potential crop evapotranspiration values. The model effectively captures the effects of extreme dry and wet conditions. In the extreme drought case, as well as extreme wet conditions, crop yields will be zero (Block *et al.*, 2008). Moreover, a CYF value of less than 0.5 leads to crop failure under normal conditions (Berger, 2001; Block *et al.*, 2008). The main source of irrigation water in the UER is surface water and rainfall, which were simulated with the distributed hydrology model WASIM-ETH. The two large-scale irrigation projects (Tono and Vea), 88 small dams and river water pumping at the White Volta River are the source of surface water supply. The available irrigation water in each irrigation site (inflow) is then shared among the model agents based on their amounts of irrigable land in that particular irrigation site.

10.3.2 Consumption decision process

To capture the consumption and poverty level in the UER, the consumption part in the model included a detailed budgeting system that allocates the income from farm and non-farm activities to savings, non-food expenditure (using a modified Working-Leser model), and food expenditure (using a Linear Approximation of the Almost Ideal Demand System (LA/AIDS)). The model captures the standard economic relationship between savings and income:

$$Y = S + TE \tag{10.4}$$

For a given household, savings is specified as a function of income and other household specific unobserved characteristics affecting savings levels.

$$S = a_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 x^{hc} + \sum_{n=1}^{n} \beta_n D + \mu_i \tag{10.5}$$

Where S is total savings from a given level of income, Y is the total disposable income, x^{hc} includes household characteristics such as sex and age and D is a vector of regional dummies, capturing differences in climate and agro-ecology.

The second stage, where household agents allocate expenditure between food and non-food items, is captured using a modified version of the Working-Leser model, following Schreinemachers *et al.* (2007). In this decision, agents allocate income after-savings into food and non-food expenditures. For this study, the modified version of the Working-Leser model is specified as follows:

$$\omega_i = \alpha_0 + \beta_1 \ln(PCE) + \beta_2 x^{hc} + \sum_{n=1}^{n} \beta_n D + \mu_i \tag{10.6}$$

where ω_i is the share of food expenditure from the total expenditure, PCE is per capita expenditure, x^{hc} are household and demographic variables and D is a vector of regional dummies. The final stage, where agents allocate food expenditure to specific food items, is parameterized using the linear version of the AIDS model. In all of the specifications, the budget share equation for each food category is specified as a function of its own price, the price of other goods in the demands system and the real total expenditure on the group of food items. Specifically the model is presented as follows:

$$w_i = \alpha_i + \sum_{j=1}^{j} \gamma_{ij}\, lnp_j + \delta_i \left(\frac{x}{\sum_{n=1}^{n} w_n\, lnp_n} \right) + \varphi_i x^{hc} + \sum_{n=1}^{n} \beta_n D + \mu_i \tag{10.7}$$

where w_i refers to the budget share of food category i, p is a vector of prices, x refers to the total per-capita food expenditure, x^{hc} is a vector of household characteristics and D is a set of regional dummies. The complete demand system for LA/AIDS was then estimated using Zellner's Seemingly Unrelated Regression (SUR) technique, imposing the additional constraints of homogeneity, adding-up and symmetry.

10.3.3 Model validation

According to McCarl and Apland (1986), model validation is an important part of empirical economic analysis. Simulation results should therefore be cross-checked through association tests between simulated results and real world observed values. Similarly, Marks (2007) pointed out that bio-economic models need to be validated at micro- and macro-level to make sure that the model realistically replicates the real world trend (Table 10.1). In this study, micro-validation is done at cluster level since clustering was made based on homogenous characteristics of households with respect to land size. The model was validated by conducting regression analyses between observed land-use values with predicted values from running the baseline scenario. The baseline reflects the current situation and assumes the current trend in demography, diffusion of innovations, prices and rainfall. A regression line was fitted through the origin for the observed and predicted land use of the main seven crops expressed in percentage to total area of these crops.

10.4 Results and Discussions

This chapter presents MPMAS simulation results divided into three sections: (i) baseline without climate variability; (ii) current climate variability; and (iii) policy interventions. The outcome indicators used are per-capita household income (to measure the impacts of policy intervention and technology diffusion) as well as minimum food

Table 10.1. *Validation results.*

Level	Slope coef	Std error	R^2
Micro (clusters)	0.99	0.08	0.96
Cluster 0	0.98	0.05	0.98
Cluster 1	1.06	0.17	0.93
Cluster 2	0.95	0.05	0.98
Cluster 3	0.94	0.06	0.96
Macro (catchment)	0.96	0.01	0.98

requirements met (to measure changes in food security).

10.4.1 Baseline without climate variability

The baseline corresponds to a hypothetical scenario constructed without any climate variability, in which each individual agent is simulated recursively over a period of 15 years. We choose the baseline as a situation without any climate variability since a lack of an appropriate comparison unit may pose challenges for impact estimation. As a baseline, one can for example use the current levels of variability as a benchmark. Without establishing how household income would have been evolved without any climate variability, however, it is almost impossible to estimate the impact of climate variability on household income. We therefore analysed the effects of climate variability on food security and poverty outcomes by constructing a baseline with and without climate variability.

Figure 10.4 shows the share of minimum consumption met at agent level under baseline conditions (i.e. under current credit availability and levels of technology diffusion) averaged for each agent over 15 years. Accordingly we found that about 69.6% of the agent population lies below this poverty line in the hypothetical case without climate variability.

10.4.2 Baseline with climate variability

In this section, we present the results of climate variability at the household level. A closer investigation at the household level, Fig. 10.5 ranks the individual agents by their baseline income in the absence of climate variability and computes income changes owing to climate variability at household level. The result reveals that the effects of climate

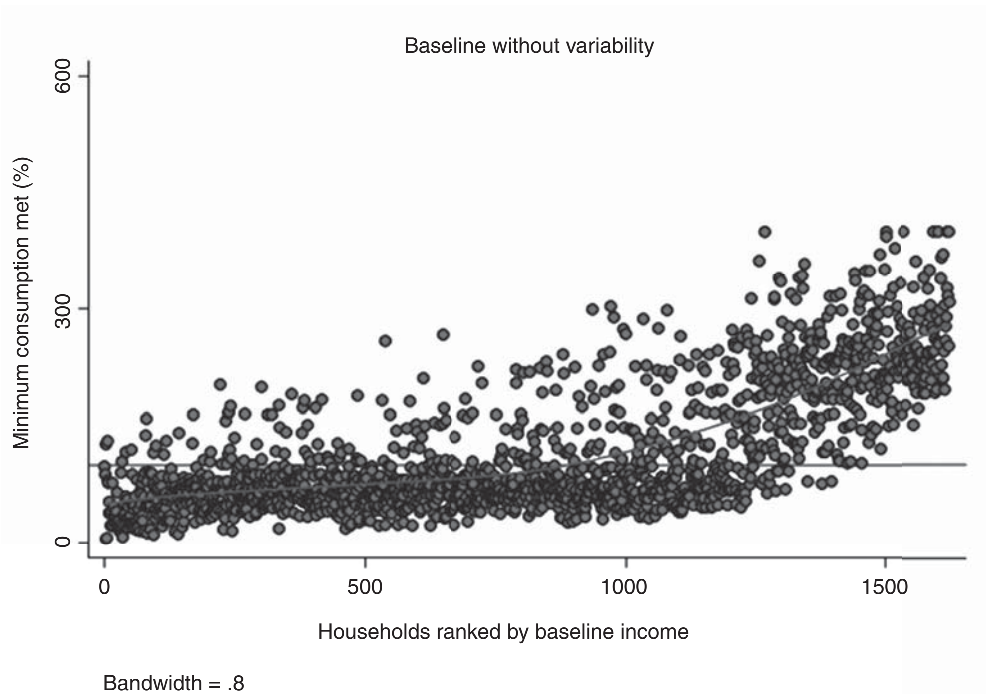

Fig. 10.4. Food security without climate variability.

Table 10.2. Effects of policy interventions.

Scenario	Income (Ghanaian Cedi)	Food energy consumption (GJ/capita)	Fertilizer use (kg/ha)
Baseline	826.8	2.82	16.5
Access to credit	1281.2	4.11	53.4
Access to off-farm	873.3	2.98	17.2
Both	1330.95	4.26	54.8

variability alone are felt disproportionately across different income groups. Specifically, the effects tend to be slightly more negative on agents with lower baseline incomes. Overall, owing to climate variability, household incomes declined by slightly more than 8% on average compared to the baseline without any climate variability.

We further estimate the impacts of climate variability on household food security using food calorie intake as a measure of food security. In the baseline, before variability, food security measured as the percentage minimum consumption met based on food energy consumption shows that about 69.6% of the agents could not meet their minimum consumption (Fig. 10.6). With climate variability, food insecurity increases to 85.99% (Fig. 10.6). Moreover, poor households have become poorer compared to the situation of no variability, implying that climate variability affects the poor with limited ability to cope.

10.4.3 Policy interventions

The adverse effect of climate variability depends on the adaptation and coping capacities of farm households. Studies by Dercon and Christiaensen (2011) and Ziervogel *et al.*

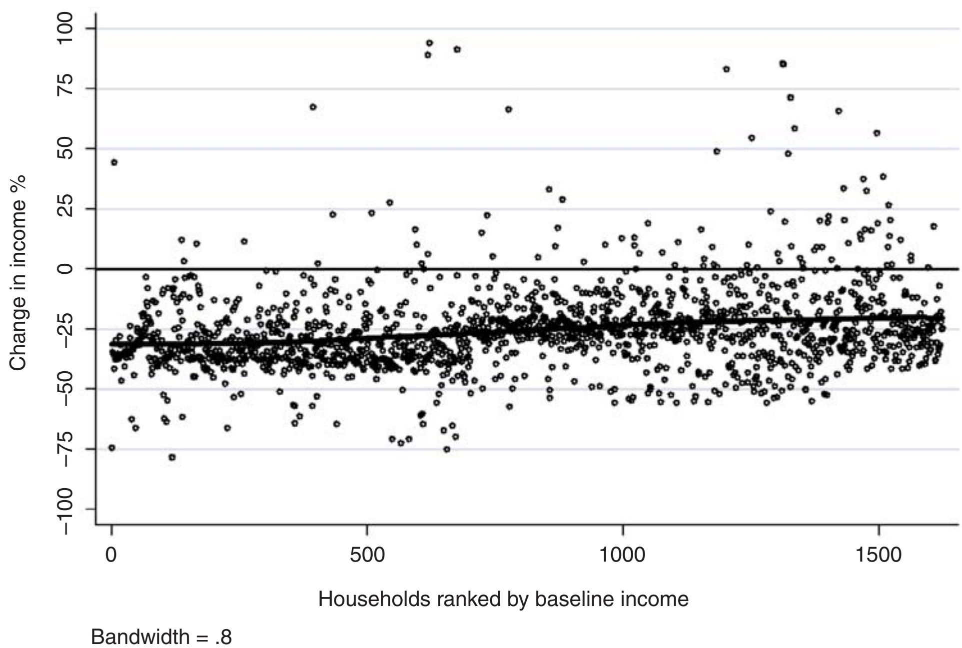

Fig. 10.5. Income changes due to climate variability.

Table 10.3. Effects of policy interventions differentiated by farm types.

	Average income (Ghanaian Cedi)		
Farm type	Baseline	Access to credit	Change (%)
Rainfed farm	620.94	760.42	0.22
Big dam farm	1109.6	2019.21	0.82
Small dam farm	1123.3	1757.25	0.56

(2006) suggested that adaptation measures implemented by households are less likely to be equally effective because households are heterogeneous in terms of income, resource endowments and adaptation capacity. Interventions and policy actions that support heterogeneity are therefore important for evaluating the effectiveness of local level adaptation measures (Berger, 2001; Ziervogel *et al*., 2006; Berger and Troost, 2013). When farmers' livelihoods are at stake, on-farm adaptation strategies such as shifting planting dates and diversifying crop types may not be feasible owing to limited access to information and capacity to cope. Under these circumstances, strategies that consider the long-term livelihood of farmers without compromising the short-term food security status of households will be needed. Mideksa (2010) for instance suggested that income sources that are less sensitive to climate variability must be the way forward. Here, we argued that given the importance of agriculture and climate-dependent activities in most developing countries in general and in Ghana in particular, this might not be the only way out in the future. Instead, policy interventions that boost production while

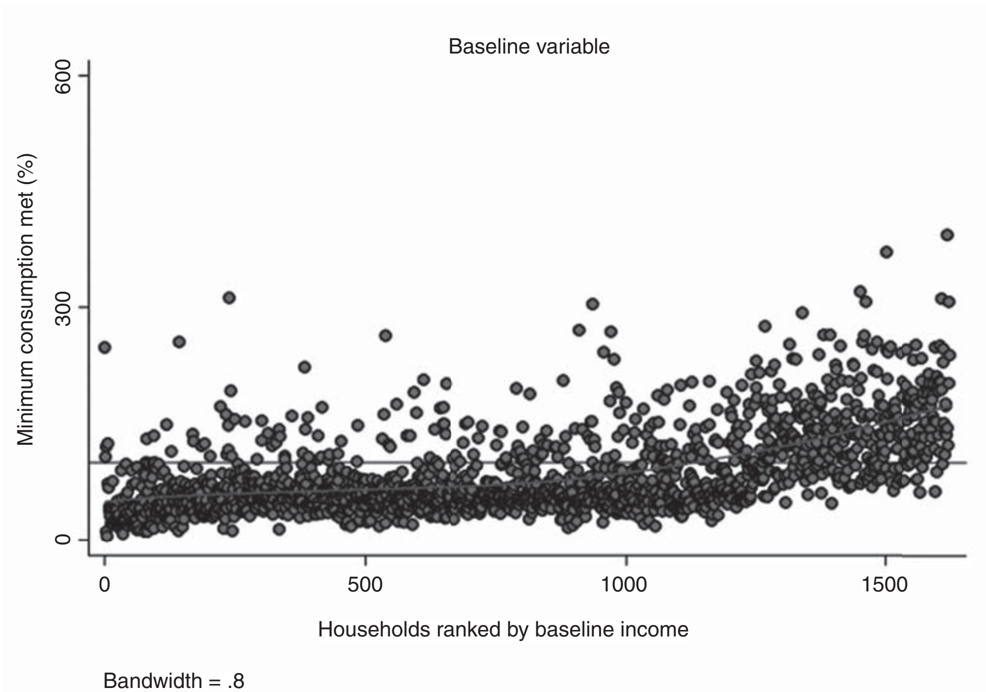

Fig. 10.6. Food security changes due to climate variability.

combining an element of diversification of income sources must be advocated. This kind of policy intervention, for example, can be providing simultaneously production credit and off-farm income-generating opportunities.

It has been well documented that poor agricultural households in many developing countries lack adequate access to credit in order to invest enough to get productivity gains in light of climate variability (Ellis, 2000). Moreover the absence of credit markets has forced households in many developing countries to engage themselves in costly adaptation strategies such as selling of livestock and other assets, which aggravated poverty and food insecurity. Previous studies on climate variability adaptation have also indicated that lack of credit access has affected households' ability to change current cropping management practices such as the use of special combinations of crop varieties and cultivation practice, as well as to buy new crop varieties in response to climate variability (Berger and Troost, 2013). Studies also indicated that, in addition to providing short-term production credit, the promotion of non-farm employment opportunities plays a crucial role in enhancing food security under climate variability for poor rural farm households (Barrett *et al*., 2001; Owusu *et al*., 2011). The role of off-farm employment is even more crucial in light of climate variability as households face seasonal food shortages as a result of low productivity (Owusu *et al*., 2011).

In this section we present the results of our micro-level assessment on the effectiveness of policy interventions by examining the effects of providing access to credit and improving off-farm income-generating activities as a means of livelihood diversification and as a way of adaptation to current climate and price variability as an example. Moreover, we implemented different mixes of coping mechanisms such as selling livestock, purchase of additional food, consuming different foods, and consuming less expensive and inferior food. Some of the coping strategies mentioned above are, however, the sort of last-resort decisions those households are typically reluctant to make. These involve, for example, selling livestock or changing consumption patterns. The purpose of doing policy analysis on the effects of climate and price variability with and without policy interventions is threefold: (i) in addition to determining the effects of climate and price variability on food security and income changes, it would also be possible to analyse how effective policy interventions are in helping households cope with the adverse effects of climate variability; (ii) ex-post assessment on the roles of different policy interventions on different income groups can be made for targeted interventions instead of a 'one size fit' policy approach; and (iii) it would also be possible to determine which adaptation strategy and policy intervention mixes are optimal for reducing the adverse effects of climate and price variability.

Access to credit and off-farm employment

To relax capital constraints, all households in the model are given access to short-term production credit. Our simulation results show that access to credit would enable households to change their land use from subsistence rainfed farming to high-value crop irrigation farming. Even with an interest rate of 25%, the model suggests that households apply for farm credit and expand their area under irrigation farming. The simulation results further show that access to credit would probably increase the average household income and food energy consumption (Table 10.2).

The application of mineral fertilizer (in kg/ha) could also triple with the access to credit, which would help to improve the sustainability of agricultural land use in the region. In UER, due to imperfect credit markets, the capital required for irrigation in the dry season is financed through off-farm income sources like dry season migration to nearby towns, small trading, charcoal burning and off-farm labour. The econometric study by Yilma (2005) revealed that irrigation practices during the dry season and off-farm income are complementary to each other even though both activities are taking place in the same season. The multi-agent model is used to analyse the impacts of access to dry season migration on household income and food security. The scenario assumed that the number of persons migrating from each household should not exceed more than two adults. The simulation results showed that access to dry season migration has marginally increased the income of the farm households compared to baseline income (Table 10.2). The results also indicate that the income from off-farm employment is utilized to finance irrigation farming, which is evident from the increase in the total area under irrigated crops when compared to the baseline scenario. The results indicate that, in the presence of market imperfections, the cash-constrained households in UER use their labour force off-farm to finance the irrigation farming.

The impacts of credit on welfare of the different farm types are analysed and given in Table 10.3. The simulation results show that access to credit could increase the income of farmers with irrigation access (small dam and big dam farms) by 56% and 82% respectively compared to the baseline income level, whereas the income of the rainfed farms would increase only by 22%. The results indicate that farm households who have physical access to irrigation would be benefiting more by availing credit than subsistence rainfed farmers. We conclude from this policy scenario that providing access to credit without expansion of irrigation facilities in the region would not give the intended result of improving the livelihood of poor subsistence rainfed farmers.

The kernel density distributions of poverty for different scenarios are given in Fig. 10.7. Access to credit can reduce poverty substantially; most of the poor households could cross the poverty line (3.259 BJ/capita/year). The distribution graph also shows that the poorest agents would not benefit from access to credit because the tail of the distribution has not changed. This is mainly because the poorest agents are those without physical access to irrigation and providing credit for rainfed farming is not so profitable. So the poverty status of the poorest agents would probably not change even under favourable policy interventions.

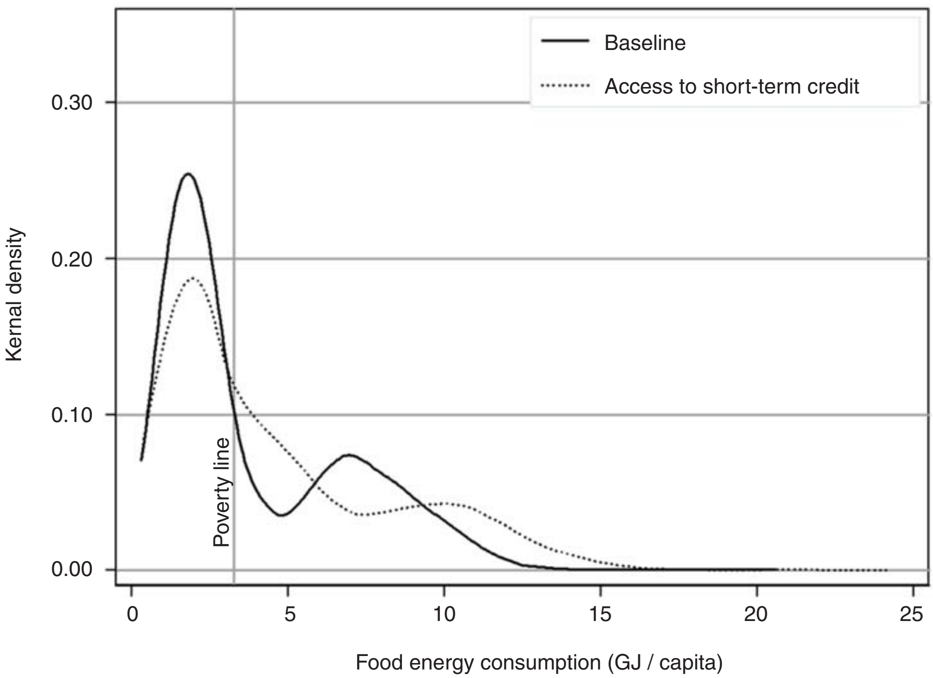

Fig. 10.7. Role of credit on food energy consumption.

10.5 Summary and Conclusion

This chapter employed an agent-based modelling approach to quantify climate variability effects in the context of Ghana. The agent-based modelling approach employed in this thesis further captures the non-separability of production and consumption decisions by parametrizing consumption, innovation and production behaviour of households through micro-econometric techniques. Further, by combining disaggregate socio-economic and climate/crop data, the study quantified the impacts of climate variability on food security and poverty at the household level. In doing so, this chapter provides potential entry points on how specific adaptation strategies and policy interventions, especially those related to the promotion of improved credit, irrigation and off-farm employment, might affect the distribution of household food security and poverty outcomes.

Our results on the effects of climate variability have many relevant policy implications. Even without the absolute magnitude of the effects, policy makers can use the results of this chapter to identify vulnerable groups to climate variability. Given that 'self'-coping strategies were not sufficient in shielding households against the impacts of climate and price variability, policy interventions designed to improve the asset-base of farm households will be very important. In addition, provision of other ex-post coping mechanisms will be important to avoid households engaging in coping mechanisms that erode their assets. These include, for example, coping through the sale of livestock, which might lead to long-term asset poverty traps. As such, considering the long-term implication of climate variability on a household's ability to recover from such shocks and poverty traps must be taken into consideration. In addition, well-targeted consumption credits, such as food for work and other production-oriented safety nets, will be important in reducing the impacts of variability while also improving productivity. In areas where agricultural productivity is very low or where production potentials are very limited, moving away from agriculture or diversification of livelihood is important.

Further, in addition to improving the coping ability of farm households, policy interventions designed at improving the *ex ante* adaptive capacity of farm households will be very crucial. Our analysis on the effectiveness of adaptation options clearly showed that policy interventions aimed at improving the provision of short-term production credit along with the current irrigation facilities are effective in reducing the adversity of climate variability. Policy interventions through a single course of intervention, either through credit or irrigation alone, are likely to fail, however. The need for a mix of interventions is therefore important if the adverse effects of climate variability are to be reduced. As a result, under circumstances where access to irrigation is only available with unaffordable prices or without access to credit, such an intervention may fall short in achieving the intended results. As such, policy makers must create sound institutional capacities to insure that such interventions are accessible to poor farm households.

While designing adaptation options, a clear distinction should also be made on what is needed in the short run and in the long run. Even though short-run interventions aimed at improving current vulnerability are important, improving productivity requires large investments and interventions in the form of packages. Because our simulation clearly showed intervention through complementary packages is the only effective mechanism to improve livelihood under variability, strengthening institutional capacity is very crucial. These include policy interventions to improve the use of available current technologies, including irrigation and credit, and improving the use of agricultural inputs such as fertilizer through credit and off-farm income-generating opportunities. Long-term interventions aimed at improving the adaptive capacity of farm households in the long term are also necessary. These include the introduction of new crop varieties that are adapted to the local climate condition and the development and expansion of production through irrigation. The result on the distributional aspect of climate variability also suggested the need for context-specific research. This result has a wider policy and research implication. Policy makers, non-governmental organizations (NGOs) and international organizations engaged in development activities need to consider best fits instead of a 'one size fits all' intervention and researchers need to apply methods that capture farm-and household-level decision making and constraints.

Notes

1 Land values are used as dependent variables based on the assumption that, in a competitive market, the price of farmland reflects the discounted value of all the expected future profits that can be derived from it (Mendelsohn *et al*., 1994).

2 The GLSS 5 is a nation-wide survey that collected detailed information of topics, including demographic characteristics of the population, education, health, employment and time use, migration, housing conditions and household agriculture.

3 The crop-specific effect of climate variability on yield is captured through the biophysical model (CROPWAT).

References

Abdulai, A., Monnin, P. and Gerber, J. (2008) Joint estimation of information acquisition and adoption of new technologies under uncertainty. *Journal of International Development* 20, 437–451.

Adger, W.N., Arnell, N.W. and Tompkins, E.L. (2005) Successful adaptation to climate change across scales. *Global Environmental Change* 15, 77–86.

Arndt, C., Robinson, S. and Willenbockel, D. (2011) Ethiopia's growth prospects in a changing climate: a stochastic general equilibrium approach. *Global Environmental Change* 21, 701–10.

Barrett, C.B., Reardon, T. and Webb, P. (2001) Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics and policy implications. *Food Policy* 26, 315–331.

Berger, T. (2001) Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. *Agricultural Economics* 25, 245–260.

Berger, T. and Troost, C. (2013) Agent-based modeling of climate adaptation and mitigation options in agriculture. *Journal of Agricultural Economics* 66, 323–348.

Berger, T. and Troost, C. (2014) Dealing with uncertainty in agent-based simulation: farm-level modelling of adaptation to climate change in Southwest Germany. *American Journal of Agricultural Economics,* aau076.

Biggs, J.S., Thorburn, P.J., Crimp, S., Masters, B. and Attard, S.J. (2013) Interactions between climate change and sugarcane management systems for improving water quality leaving farms in the Mackay Whitsunday region, Australia. *Agriculture, Ecosystems & Environment* 180, 79–89.

Block, P, Strzepek, K. and Diao, X. (2008) Impacts of considering climate variability on investment decisions in Ethiopia. *Agricultural Economics* 39, 171–181.

Busby, J., Cook, K., Vizy, E., Smith, T. and Bekalo, M. (2013) Identifying hot spots of security vulnerability associated with climate change in Africa. *Climatic Change* 124, 717–731.

Chijioke, O., Haile, M. and Waschkeit, C. (2011) Implication of climate change on crop yield and food accessibility in sub-Saharan Africa. Interdisciplinary term paper. University of Bonn, Bonn, Germany.

Clarke, D., Smith, M. and El-Askari, K. (1998) *CropWat for Windows: User Guide*. University of Southampton, Southampton, UK.

Dercon, S. and Christiaensen, L. (2011) Consumption risk, technology adoption and poverty traps: evidence from Ethiopia. *Journal of Development Economics* 96, 159–173.

Di Falco, S. (2014) Adaptation to climate change in sub-Saharan agriculture: assessing the evidence and rethinking the drivers. *European Review of Agricultural Economics* 41, 405–430.

Di Falco, S. and Bulte, E. (2013) The impact of kinship networks on the adoption of risk mitigating strategies in Ethiopia. *World Development* 4, 100–110.

Di Falco, S. and Veronesi, M. (2014) Managing environmental risk in presence of climate change: the role of adaptation in the Nile basin of Ethiopia. *Environmental Resource Economics* 57, 553–577.

Ellis, F. (2000) The determinants of rural livelihood diversification in developing countries. *Journal of Agricultural Economics* 51, 289–302

FAO (1996) *Rome Declaration on World Food Security*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2008) *Climate Change Adaptation and Mitigation in the Food and Agriculture Sector*. FAO, Rome, Italy.

GLSS (2008) *Ghana Living Standard Survey (GLSS) Report of the Fifth Round.* Ghana Statistical Service. September 2008.

Gyasi, O, Schiffer, E. and McCarthy, N. (2006) Community needs assessment and local water governance appraisal in the Upper East Region, Ghana. Draft, Submitted to EPTD Discussion Paper, International Food Policy Research Institute, Washington DC.

Hertel, T., Burke, M. and Lobell, D. (2010) The poverty implications of climate-induced crop yield changes by 2030. *Global Environmental Change* 20, 577–585.

Holden, S. and Shiferaw, B. (2004) Land degradation, drought and food security in a less favoured area in the Ethiopian highlands: a bio-economic model with market imperfections. *Agricultural Economics* 301, 31–49.

Jack, K.B. (2011) *Market Inefficiencies and the Adoption of Agricultural Technologies in Developing Countries*. Literature review, Agricultural Technology Adoption Initiative, J-PAL (MIT) and CEGA (UC Berkeley), USA.

Krishna, A. (2001) Moving from the stock of social capital to the flow of benefits: the role of agency. *World Development* 29, 925–943.

Lippert, C., Krimly, T. and Aurbacher, J. (2009) A Ricardian analysis of the impact of climate change on agriculture in Germany*. Climatic Change* 97, 593–610.

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

Marks, E. (2007) Validating simulation models: a general framework and four applied examples. *Computational Economics* 30, 265–290.

McCarl, B. and Apland, J. (1986) Validation of Linear Programming Models. *Southern Journal of Agricultural Economics* 18, 155–164.

Mendelsohn, R., Nordhaus, W.D. and Shaw, D. (1994) The impact of global warming on agriculture: a Ricardian analysis. *The American Economic Review* 84, 753–771.

Mideksa, T. (2010) Economic and distributional impacts of climate change: The case of Ethiopia. *Global Environmental Change* 20, 278–286.

Nedumaran, S., Shiferaw, B., Bantilan, M.C.S., Palanisami, K. and Wani, S.P. (2014) Bioeconomic modeling of farm household decisions for ex-ante impact assessment of integrated watershed development programs in semi-arid India. *Environment, Development and Sustainability* 16, 257–286.

Nelson, C., Rosegrant, W. and Koo, J. (2007) *Climate Change Impact on Agriculture and Costs of Adaptation*. International Food Policy Research Institute, Washington, DC.

Nelson, G.C., van der Mensbrugghe, D., Ahammad, H., Blanc, E., Calvin, K., *et al.* (2014) Agriculture and climate change in global scenarios: why don't the models agree? *Agricultural Economics* 45, 85–101.

Owusu, V., Abdulai, A. and Abdul-Rahman, S. (2011) Non-farm work and food security among farm households in Northern Ghana. *Food Policy* 36, 108–118.

Schreinemachers, P. and Berger, T. (2011) An agent-based simulation model of human environment interactions in agricultural systems. *Environmental Modelling & Software* 26, 845–859.

Schreinemachers, P., Berger, T. and Aune, J.B. (2007) Simulating soil fertility and poverty dynamics in Uganda: a bio-economic multi-agent systems approach. *Ecological Economics* 64, 387–401.

Shiferaw, B., Okello, J. and Reddy, R. (2009) Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. *Environment Development and Sustainability* 11, 601–619.

Smith, M. (1992) *CROPWAT, A Computer Program for Irrigation Planning and Management*. FAO Irrigation and Drainage Paper 46. Software 26, 845–859.

Woelcke, J. (2006) Technological and policy options for sustainable agricultural intensification in eastern Uganda. *Agricultural Economics 34*, 129–139.

Wossen, T. and Berger, T. (2015) Climate variability, food security and poverty: agent based assessment of policy options in Northern Ghana. *Environmental Science and Policy* 47, 95–107.

Wossen, T., Berger, T., Nedumaran, S. and Ramilan, T. (2014) Climate variability, consumption risk and poverty in semi-arid Northern Ghana: adaptation options for poor farm households. *Environmental Development* 12, 2–15.

Yilma, T. (2005) Modeling farm irrigation decision under rainfall risk in the White-Volta basin of Ghana, PhD Thesis, Faculty of Agriculture, University of Bonn, Germany.

Ziervogel, G., Bharwani, S. and Downing, T. (2006) Adapting to climate variability: pumpkins, people and policy. *Natural Resources Forum* 30, 294–305.

11 Moving Along Adaptation Pathways Toward Grass-root Resilience: A Synthesis

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Abstract

This chapter reports on cross-country evidence from the micro (farm-level) analysis on impacts, adaptation and vulnerability to the ever-rising climate-related risks. It has also identified the common challenges across countries, as well as unique features within regions, countries and continents. The challenges include excessive stress on natural capital, increasing demand for physical and financial resources and social capital. Through extensive data collection and analysis it also identifies deficiencies in future planning and country-specific strategies, policies and programmes. These deficiencies and their implications for the future on the farm households are highlighted comprehensively in these selected countries of Asia and Africa.

11.1 Introduction

This chapter assimilates the micro-level studies conducted in different regions of Asia and Africa. We took stock of the various experiences to come up with strategies/measures that farmers are practising at the micro-level. Here we also discuss the constraints to adaptation as perceived by the farmers and identified opportunities in mainstreaming adaptation and enhancing climate-resilient agriculture.

11.2 Adaptation Measures: How Farmers are Practising at Micro-level

A summary of the adaptation measures used at various levels is presented below, drawing from the conceptual frame presented. The summarizing is at the four levels of action required, i.e. household, community, national and global. The strategies adopted at the household level are a result of several factors, as presented in the conceptual model (Fig. 11.1).

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Fig. 11.1. A framework for synthesizing adaptation strategies at ground level and enabling conditions.

It is well known and widely accepted that farmers are rational and also conservative, and the majority are risk averse. The prevailing array of practices adopted by farmers in each village is unique and specific to the location, with some commonalities in the regions. The practices adopted at present are a result of the following factors.

At the household level:

1. Intergenerational knowledge transfer based on primarily experiential learning
2. Household resource base – savings, assets, wealth, skills and competencies, social contacts

At the community level:

1. Leadership
2. Collective ethos guiding action for community interests
3. Groups addressing common needs
4. Penetration of external agencies
5. Resource base – land, water, forests, infrastructure

At the national/governmental level:

1. State agencies with extended mandates to the periphery
2. Supporting legislation and institutions that enable households and communities to act considering local context
3. Resource transfer to the periphery

At the global/regional level:

1. International agreements and conventions
2. Interagency programmes
3. Regional initiatives and programmes

The situation in each of the countries and study locations is elaborated below and a summary of specific adaptation strategies classified by levels of action is presented in Table 11.1.

11.2.1 India

Adaptation measures exercised by the farmers in the six villages shown below are elicited from interactions with the farmers through various means. Most of these adaptation measures are autonomous and the farmers chose them to address the changing situations, and it may not necessarily be due to climate variability, but quite often a complex situation arising out of a combination of reasons.

Aurepalle

- There has been the adaptation of improved varieties and short-duration crops and varieties.
- Farmers slowly went for cash crops in the place of cereals as an adaptation measure, at present dominated by cotton cultivation on more than 70% of the area.
- During the last decade farmers in the village rapidly formed as many as 45 various self-help groups (SHGs). Notable among them are a few micro-finance groups to get easy access to capital for their farm inputs and other needs. This is a viable adaptation strategy to the increasing risk of agriculture.
- In the most recent decade, three new milk collection centres came up in the village and this is seen as evidence that an increased diversification of incomes

Table 11.1. Summarized information on adaptation strategies or initiatives adopted at different levels among the countries/regions.

Sl. No.	Adaptation strategies adopted at different level of organization	India	Sri Lanka	Bangladesh	Thailand	Vietnam	China	Africa
	Household level:							
1	Intergenerational knowledge transfer based on primarily experiential learning:							
	Adopt improved varieties and short-duration crops	√	√	√				
	Substitute cash crops for cereals	√		√			√	
	Drought-tolerant crops, i.e. cotton, sorghum	√				√		
	Dig tube wells to supplement water supply	√				√		
	Adaptation of improved short duration varieties	√						
	Reduce high water requiring rice/crops cultivation	√						√
	Adopt mixed cropping including low water requiring crops i.e. castor and pigeonpea	√			√			
	Shifting to mono-cropping of soybeans	√						
	Increase sugarcane or other high value cultivation (canal irrigation)	√			√			
	Delayed cultivation to conserve rainwater	√						
	Income diversification (dairy, fish farming)	√	√	√		√		
	Wheat cultivation during rabi with supplementary irrigation	√						
	Change from seasonal to perennial crops				√			
	Changing traditional/seasonal crops to short duration cash crops/ high-value crops		√				√	
	Farm mechanization		√					
	Adaptation of hybrid varieties		√					
	Work as labour					√	√	√
	Diversification to non-farm income source	√			√			
	Migration	√		√			√	√
	Enriching soil fertility through organic amendments (organic manure)				√			

continued

Table 11.1. *continued*

Sl. No.	Adaptation strategies adopted at different level of organization	India	Sri Lanka	Bangladesh	Thailand	Vietnam	China	Africa
2	Household resource base – savings, assets, wealth, skills and competencies, social contacts							
	Reduction of personal expenses	√			√			√
	Community level:							
3	Leadership	√	√					
4	Collective ethos guiding action for community interests reflected in groups addressing common interests							
	Establish self-help micro-credit groups	√	√		√			√
	Kinship support systems		√		√			
5	Penetration of external agencies							
	Establishing milk collecting centres	√						
6	Resource base – land, water, forests, infrastructure							
	National/governmental level:							
7	State agencies with extended mandates to the periphery	√			√		√	
8	Supporting legislation and institutions that enables household and communities to act considering local context						√	
9	Resource transfer to periphery							
	Input subsidies during peak requirement periods		√				√	
	Global/regional level:							
10	International agreements and conventions	√	√	√	√	√	√	√
12	Regional initiatives and programmes	√	√	√	√	√	√	√

[a] Africa related information drawn from Wossen *et al.* (2014).

away from the traditional crop production is an adaptive measure that will reduce the risk of income loss owing to increased variability of rainfall and droughts.

- Water for 'on demand irrigation' eliminates the risk associated with the variability in rainfall. Farmers recognize this as an important adaptation measure. The recent decade saw a rapid increase in tube well numbers in the village. At present there are about 212 tube wells in the village. Over the decades the exploitation of groundwater has rapidly increased.

Dokur

- There has been the adaptation of improved varieties and short-duration crops and varieties.
- Dokur has more than 50% of rice-growing area. The rice area decreased with time and more drought-tolerant crops like castor are adopted by farmers in the village.
- Mixed cropping is adopted and at present castor + pigeonpea is one of the mixed cropping systems that the farmers practise in this village.
- In the most recent decade, 15 various farmer associations and 32 self-help groups including micro-finance groups came up in the village and they are seen as an effective adaptation strategy to cope with the risk from increasing rainfall variability and droughts.
- In the most recent decade, the farmers' incomes diversified and a new milk collection centre came up in the village. The most recent decade saw a rapid increase in tube well numbers in the village and at present there are about 220 tube wells in the village. Over the decades, exploitation of groundwater has rapidly increased.

Shirapur

- There has been the adaptation of improved varieties and short-duration crops and varieties.
- Farmers in Shirapur have chosen sugarcane and now it is grown on more than 70% of their lands. This gives assured cash incomes a ready market, owing to the sugar mills that came up near the village.
- About 70% of the rainfed area is sown with sorghum in the post-rainy season with no crops grown on these lands during the rainy season to allow it to conserve moisture. Post-rainy season sorghum is grown on residual and stored soil moisture.
- In the recent decade, as many as 15 self-help groups came up in the village to cope with the risk from increasing rainfall variability and droughts.
- Farmers in this village see dairy activities as diversification of income and as an adaptive measure to reduce the exposure to increased risk of rainfall variability and droughts.
- The recent decade saw a rapid increase in tube well numbers and at present there are about 350 tube wells in the village. Over the decades, exploitation of groundwater has rapidly increased.

Kalman

- There has been the adaptation of improved varieties and short-duration crops and varieties.
- Most of the farmers grow pigeonpea under rainfed conditions during the rainy season. They have adopted improved short-duration cultivars.
- More than 70% of the cropped area is sown with sorghum during the post-rainy season as it can grow on the residual soil moisture.
- In the recent decade as many as 39 self-help groups came up in the village as an effective adaptation strategy to cope with the risk from increasing rainfall variability and droughts.
- The recent decade saw an increased number of milk collection centres and a new milk cooperative in the village. Farmers see the diversification of incomes into dairy and other areas as an adaptive strategy to cope with the risk

of depleted incomes owing to increased variability of rainfall and droughts.

- The most recent decade saw a rapid increase in tube well numbers and at present there are about 160 tube wells in the village. Over the decades, exploitation of groundwater has rapidly increased.

Kinkheda

- There has been the adaptation of improved varieties and short-duration crops and varieties.
- To address the variability of rainfall, the majority of the farmers grow mixed crops to reduce their risks of crop failure. More than 60% of the area in the rainy season is under mixed crops of soybean and pigeonpea or cotton and pigeonpea.
- Wheat is grown on the lands with supplementary irrigational facilities during the rabi season.
- In the most recent decade as many as 11 self-help groups came up in the village as an effective adaptation strategy to cope with the risk of increasing rainfall variability and droughts.
- Farmers recognize the importance of irrigation in reducing the risk of variability of rainfall. Exploitation of groundwater is not so rapid in this village.

Kanzara

- There has been the adaptation of improved varieties and short-duration crops and varieties.
- Farmers changed from growing sorghum and cotton and slowly shifted to growing soybean. At present soybean is grown as a sole crop as well as mixed crop on more than 70% of the area in the village. Farmers chose modern short duration and drought-tolerant soybean varieties to increase their income.
- As many as four different farmers' associations and 14 self-help groups came up in the village in the recent decades and farmers see them as an effective adaptation measure to cope with the risk associated with the increasing rainfall variability and droughts.
- The most recent decade saw an increase in the milk cooperative in the village and farmers see it as an adaptive measure to address the increased risk owing to increased rainfall variability and droughts.
- In this village there was a rapid expansion of the number of open wells in the recent decade (about 108 at present); irrigation is seen as an important adaptation measure by the farmers.

11.2.2 Sri Lanka

The major adaptation strategies adopted in the villages of Sri Lanka to reduce the risk of variability in rainfall are as follows.

Mangalapura village

- Change from seasonal crop cultivation to perennial crop cultivation.
- Providing subsidy to input requirements.
- Use of short-duration varieties, hybrids and drought-tolerant varieties.
- Establishment or strengthening of kinship ties.
- Diversification of means of livelihood by marginal and small farmers.

Gaalahitiyagama village

- Changing from traditional crops to short-duration cash crops as a major adaptation.
- Adapted a short-duration hybrid maize variety (Pacific) as a cash crop.
- Input subsidies at the peak requirement period.
- Introduction of mechanization and adaptation of hybrid varieties.
- Establishing kinship ties to aid at difficult times.

Bata-Atha village

- Input subsidies provided at the peak requirement period for cultivation.

- Diversification of means of livelihoods by marginal and smallholder farmers.
- Shifting from seasonal crop cultivation to short-term cash crops.

11.2.3 Bangladesh

Adaptation to climate change is seen as a strategy to face changes in climatic variables and minimize their impacts on the life and livelihood activities. Adaptation measures are usually taken to address the uncertainties in the weather elements such as rainfall. Farmers at the micro-level have been facing such rainfall variability from season to season. They are adjusting their agriculture to best address the variability. This study tried to capture the farmer's adaptation measures in the marginal environments.

Drought-prone villages

BOIKUNTHAPUR AND KHUDAIKHALI VILLAGES

- Farmers are turning to irrigation-based Boro rice and maize cultivation to address rainfall variability.
- Jute cultivation saw a major decline owing to uncertainties in rainfall and non-availability of water bodies for jute retting.
- Traditional crops like mustard and other cereals are on the decline.
- Temporary migration of smallholder and marginal farmers is increasing.
- Contribution of income from non-farm activities is increasing.
- Cultivation of traditional cereals and oilseeds were partly replaced by betel leaf cultivation.

Flood prone villages

NISHIAGUNJ VILLAGE

- Farmers have diversified with fish cultivation or aquaculture in their fields.
- Traditional cultivation of rice got reduced and fish cultivation replaced most of the rice cultivation.
- Jute cultivation has declined drastically in recent times.

PASCHIM BAHADURPUR VILLAGE

- Farmers are no longer cultivating jute because it needs plenty of water for processing.
- Jute is replaced by several pulses, vegetables and tobacco.
- Wheat cultivation has also declined because of farmers' perception that the winter duration has decreased.
- Due to increased rainfall variability Aus rice cultivation has declined.
- Better access to micro-finance is seen as another adaptation measure by the farmers.
- There has been improved mechanization in recent times.

11.2.4 Thailand

Lowland villages

Migration was very high in Don Plai village during the severe drought of 1981–1982, the most unforgettable tragedy to the farmers of the village. They recollect that all the able-bodied villagers left the village leaving the very young and old in the village. The entire rice crop was lost.

Adaptation measures that the farmers of Don Plai and Kudsawai villages followed over the years that came up during the focus group discussions are shown below:

- Decreased their personal expenses.
- Medium and large landholders store rice for their own consumption instead of selling in the markets.
- Temporary migration in times of extreme events.
- Income diversification through handicraft making (in Kudsawai village) and working as factory labour.
- Grow less water-demanding crops such as cassava, or more short-duration crops like maize.
- Delayed planting of rice.
- Change from transplanting to broadcasting of rice.
- Shift cassava growing to marginal lowlands to prevent the effect of longer dry spells.

- Small and large farm holders access loans to invest in better inputs and irrigation.
- Soil improvement using organic matter and crop residues.
- Increasing crop intensity as the irrigation potential has improved due to construction of canals.

Farmers' adaptation strategies in the upland villages

- Farmers reduced their personal expenses.
- They sometimes borrow money from their friends and relatives.
- Digging and deepening wells in the village.
- Change from transplanting to broadcasting rice.
- Growing kenaf/roselle was stopped due to less availability of water for processing.
- Increased irrigation facilities on a fraction of the land encouraged sugarcane growing as a cash crop, and switched to short-duration crops like maize.
- Income diversification from non-farm sources such as silk weaving, etc.
- Access to loans from cooperative societies and banks to invest in agriculture.
- Soil improvement through organic inputs and incorporation of crop residues.
- Increasing crop intensity through growing vegetables (Tha Taeng village).

11.2.5 Vietnam

Farmers in both Phuoc Nam and Phuoc Dinh communes have followed the adaptation measures described below:

- Shift to less water-demanding crops.
- Investments to establish cash crops and on increased irrigation infrastructure by large farmers.
- Diversification into livestock, especially poultry, for reducing risk.
- Improving water sources by deepening wells, desilting ponds and tanks.
- Shift to aquaculture in Phuoc Dinh commune.
- Working as farm labour to supplement the farm income (specially marginal and smallholder farmers).
- Diversifying into part-time business and salaried service to supplement income.

11.2.6 China

Among all the countries, China has a different path and the government has a decisive role in the farmers' adaptation measures. In the rest of the countries, most of the adaptation measures that the farmers have implemented are autonomous. In the case of Chinese farmers, almost all the adaptation measures are guided by the government and seem to go towards climate-smart measures. The following are some of them that have evolved from the study.

Protect and increase the forest cover around the villages

The government planned to transform around 60% of the land around Lucheba and Dajiang villages into forests. Now the forest coverage is close to 40% around Lucheba and 20% around Dajiang. It was estimated that one growing tree could absorb 18.3 kg of CO_2/annum. If there are roughly 2 tonnes of CO_2 emission per farmer in 1 year, to balance that 110 trees, or 0.13 ha of forest land is estimated to be needed. On the basis of these calculations the government is planning an afforestation drive.

Saving power and developing several alternative renewable power sources

The installation of biogas tanks: the government estimates that one tank could save 700 kWh of electric power per year if 1 hour of biogas per day is used. It could thus reduce 1.5 tonnes of CO_2 emission, which is estimated as equal to a single farmer's carbon emission. About 75% of the households are covered by biogas installations.

The government is also taking initiatives in the implementation of all the following measures:

- Saving power by installing power efficient lamps.
- Reduction in the use of coal.
- Reduction in the use of firewood.
- Saving gasoline in farm operations.
- Using solar power.

Enhancing infrastructure development

The government is improving the infrastructure for irrigation:

- An irrigation and drainage system developed by the government in Lucheba village to supply water through a pipeline to the farm gates in the village.
- Increase and improve the farm mechanization to increase cropping intensity.
- Construction of small water tanks: About 300–400 small water tanks (storing 4–6 m^3 water) were constructed in Lucheba village since 2003, which provides water for supplementary irrigation for the crops.
- Changes to the cropping system by increasing the cropping intensity.
- Farmers increasing cropping intensity by shifting from traditional cereal production to vegetable cultivation and taking three to four crops in a year.

11.3 Constraints to Adaptation as Perceived by the Farmers

Adaptation to any change in the system is essential to sustain the productivity and profitability for the farmers. Usually, the changes in the system, be it physical, economical, sociological or political, do not come as an isolated phenomenon specific to that field. In a real situation the changes are usually manifested in a complicated way. Quite often there will be a combination of changes ranging from physical to economic to administrative. Farmers usually go for autonomous adaptations in response to these complex changes, keeping in view their adaptive capacities and optimizing their resources. Quite often the disadvantaged sections like marginal and smallholder farmers are kept away from adapting such measures owing to several constraints. The following are some of the identified constraints across the villages in each country and across the selected countries in Asia.

11.3.1 India

The interactions with the farmers in the study villages and longitudinal panel data highlighted the following constraints faced by Indian semi-arid tropical farmers in the adaptation of suitable measures.

Field level:

- Non-availability of drought varieties.
- Difficulty in supplementary irrigation.

Farm level:

- Lack of access to information on climate.
- Non-availability of potential technologies including improved varieties.
- No capacity for crop diversification.

Institutional level

- Access to credits against risk.
- Efficient co-operatives/association tackling risks.
- Efficient governance.
- Lack of incentives to adopt soil and water conservation practices.
- Lack of efficient market access to the produce.

Technological level:

- Decreased ground water availability.
- Lack of improved technology to recharge groundwater.
- Lack of water-efficient crop varieties.
- Lack of information on water-efficient crops.

Social level:

- Labour shortage.
- Population increase.
- Fragmentation of farms.
- Lack of a collective approach.
- More efficient infrastructure, namely roads, hospitals, veterinary clinics, etc.

Economic level:

- Lack of availability of non-farm income during drought period.

11.3.2 Bangladesh

Most of the respondents have reported some barriers to adopting the possible adaptation measures against climatic vulnerabilities. There have been studies to identify the policies that would improve resilience in Bangladesh (Khatun and Nazrul Islam, 2010) and constraints identified from the studies from Bangladesh are listed below.

Inadequate infrastructure

Poor infrastructure is the major obstacle to adaptation. Better roads and communication facilities and marketing opportunities are identified as important drivers of adaptation.

Lack of suitable seeds

To minimize the negative consequences of droughts, floods and waterlogging, soil salinity and salt intrusion, climate-tolerant seeds are considered very effective. To adapt to such adversities new varieties of crops should be made available for the farmers.

Inadequate irrigation facilities

Rainfall variability has forced farmers to depend more on irrigation for cultivation. But inadequate irrigation facilities are a major concern. Owing to the non-availability of water, farmers have restrained themselves from rice (mostly the Aus variety), jute or cereal cultivation in many villages. According to the villagers, improved irrigation facilities (using ground or surface water) can enhance their adaptation capacity and increase their productivity.

Lack of credit facilities

Several NGOs and micro-finance institutes such as BRAC,[1] Grameen Bank,[2] ASA[3] and other local NGOs are currently working in rural Bangladesh and provide micro-credits. But no NGO provides credit to cope with the climate extremes, floods or drought. Due to the lack of institutional credit, after the incidence of climatic catastrophe the villagers had to take loans from informal channels, which leave them in perpetual debt traps.

Crop insurance

According to the farmers, the introduction of a crop insurance system may help them reduce the climate-related risks. Although the government has given permission to privately owned enterprises to set up ‘crop insurance’ schemes, there is a need to take the initiatives comprehensively to cover the most vulnerable areas of the country.

Lack of agriculture extension services

The local agriculture officer generally does not visit villages to provide expert suggestions to farmers on better adaptation practices that can be easily adapted by the farmers. It is very important to strengthen and make available proper extension services at the village level to undertake and implement adaptation policies successfully.

11.3.3 Thailand

On the basis of the interactions with the farmers and the farmers’ perceptions on adaptive capacities, the barriers that were identified that need to be addressed for creating an enabling environment for adaptation to change are shown in Table 11.2 (Adaptation Knowledge Platform, 2010).

11.3.4 Vietnam

Discussions with farmer groups, local authorities in Phuoc Nam and Phuoc Dinh communes highlighted the constraints to adaptation by the farmers shown in Table 11.3.

Table 11.2. Barriers to adaptation and reasons in different villages of Thailand.

Barriers to adaption	Reasons
Don Plai	
Recommended adaptation strategies not within priority needs of farmers, e.g. producing compost	Income-generating activities most important
Small landholding farmers	Less opportunity to change cropping pattern
Kudsawai	
Many small landholding farmers	Less opportunity to change cropping pattern and cost limitation
Most cropping areas are on a very low flood plain	A few rice varieties available and suitable for both area and market needs
Hard to adopt new methods or recommendation in improving soil fertility, e.g. compost and bio-fertilizer production and usage	Lack of knowledge and not realizing the importance of soil improvement
Nong Muang	
Lack of water source in the dry season	The village and growing areas are higher than the natural river (Chee River) and the existing water sources have not recovered after the rainy season
Lack of better crop production technology especially for rice which needs more water, e.g. drought-tolerant varieties	Deep groundwater level
Little innovation on alternate sources of income in the village	No access to seed supply and technology
	Temporary migration is easier as the road is in the village
Tha Taeng	
Hard to adopt new methods or recommendation in agriculture and need successful evidence	Too risky to lose income
	Got used to the former practice
Large farm holders ignore onset of rainfall in planning to grow crops but more consideration is given to crop types and land suitability	Having large areas provides easy decision making in growing various types of crops without awareness of climate variability

Table 11.3. Micro-level constraints to adaptation in Vietnam.

Constraints	Reasons
Technical	Technologies are available but the farmers were not able to afford them, some are not effective and lack of subsidies makes them inaccessible
Financial	Financing is available but, due to lack of collateral for borrowing, farmers are not able to use them
Social	Low education level, small farm sizes, remote and inaccessible areas
Economical	Low profits, high investment for adaptation, higher risk of crop failures
Institutional	Little or no attention to the smallholder farmer

11.3.5 China

Barriers to adaptation

China is still a developing country. In poor areas, especially in rural areas, farmers still live under low standards of living. For them ecosystem protection and perception of climate change are not high priorities. So there is a need to create awareness among the farmers on climate change and related implications, adapt and take appropriate action to mitigate climate change.

There are still some conflicts between agri-production and ecosystem protection, such as to open sloping wasteland, increase runoff and soil erosion, increased goat numbers on hilly and marginal lands that increases grazing pressures and destroys young trees and grasses, and causes heavy erosion.

Economic barriers

Farmers' income is still at a low level and farmers do not want to invest in adaptation measures. A lot of financing is needed for rural development, rural infrastructure construction, transportation, communication, power supply and technical support and so on. This would be a long-term development. This means rural development will have to take place gradually.

Technological barriers

Technological advancements such as new drought-tolerant crop varieties, modern water-saving management technologies, new environmentally friendly power sources and power-saving technologies are needed by the farmers.

Infrastructural barriers

Rural roads, water supply and drain systems, rural communication, drinking water systems, ecosystem protection and agricultural machinery need to be developed.

Barriers in policy

Government policy still plays important roles in rural development in China. To mitigate the impact of climate change, policies are needed to adjust to suit the changed situation. For example, it was suggested that the biogas tank project is no longer needed for the addition of new tanks in the two villages. There is a need to repair and manage them. But government funds are allocated to construct new tanks. The 'save power lamp' project needs more support in rural areas and needs more subsidies in rural areas than in cities. For the solar water heater project, only 13% of government funds are allocated, which is not enough. Installation of solar water heaters in rural areas is much easier than in cities because the farmers have independent houses as dwelling units.

Farmers perceived that afforestation needs more protection, and there is a need for clarification on such forest ownership and for improving planting technology and planting quality.

11.4 Opportunities for Mainstreaming Adaptation and Enhancing Climate Resiliency

The following section details various options that will empower farmers by enhancing the income and livelihoods and cushioning them from various shocks and weather aberrations. These opportunities emerged from understanding the perceptions of the farmers that were elicited in the 26 study villages across South Asia, South-east Asia and China. Though enumerated under each of the countries that participated in the study, the list may be considered as a menu of options for further assessment, modification and adoption by any entity.

11.4.1 India

- The development and diffusion of drought-tolerant and short-duration crop cultivars would aid farmers.
- Common property resources (CPRs) like tanks may be revived by collective action and suitable incentives for proper management and facilitating the flow of runoff into them.
- Advance information on the weather will help the farmers to implement timely management options and minimize losses owing to adverse events. More accurate crop-weather advisories will help the farmers achieve this.
- Weather/crop insurance programmes shall effectively help in tackling climate risks.
- Weather-based agro-advisories at the micro level are to be planned. This would help to gear up to take protective measures in the future.
- Crop planning for all good/bad weather situations should be made, which would act as a ready reckoning to take decisions.
- Diversifying and improving income sources through livestock using an adaptable breed could be achieved through efficient management.
- Improved technologies such as new crops that will be more profitable,

shorter in duration and require less water, and improved water and crop management options will help the farmers to stabilize their production.

- Farmers, and particularly the smallholder and marginal farmers, are given credit/loan on easy terms and a high subsidy given on the interest that they have to pay on the loans. This will help the resource-poor farmers to succeed in practising suitable adaptation measures.
- The establishment of efficient co-operatives and associations/groups could tackle the critical needs of farmers such as resource mobilization, marketing their outputs and efficient natural resource management.
- The present governance structures that monitor and administer the welfare activities are perceived by farmers to be more bureaucratic, difficult to approach and less transparent. There is a need to reform them for the smooth flow of funds and information to the farmers.
- Soil and water conservation practices are important in bringing long-term sustainability of the systems. But the immediate gains for the farmers are not visible. Farmers must be given incentives to adopt such practices.
- Market access for the outputs of the farmers is not direct for many villages. Usually either the local agents act or the farmers have to go a long distance with their produce. A better access will help the farmers in earning more margins.
- Suitable technologies should be made available to the farmers that will reduce the water use at the present levels. Farmers are facing a drastic reduction of groundwater levels and suitable technologies that will reduce field water losses will help the farmers to reduce their water use.
- Suitable technologies to improve water productivities of the crops and development of cultivars that are less water demanding are made available to farmers.
- Building road connectivity, markets and information gateways will assist farmers.
- Creating institutional arrangements to encourage farmers towards collective action in the management and use of natural resources (Shiferaw et al., 2009).
- The creation of opportunities in the non-farm sector in and around the villages could help the farmers diversify their incomes.

11.4.2 Bangladesh

- Farmers identified the need for better infrastructure such as roads, marketing infrastructure.
- Development and diffusion of new varieties that are drought tolerant, short duration in nature, flood-tolerant rice cultivars and salinity-tolerant cultivars are needed.
- Farmers perceive that improved and increased irrigation potential through surface and groundwater sources will improve their production sustainability and productivity.
- At present a credit facility is not available to cover the risk of extremes like droughts and floods. This is leading the farmers into perpetual debt traps. Creating easy access to credit and a high component of subsidy on the interest will help the resource-poor farmers.
- Farmers feel that crop insurance will help them cover the risks but the present scheme of crop insurance is with private players and the farmers perceive that it is not universal in its coverage. A universal crop insurance scheme will help the farmers.
- A better extension infrastructure that will improve the access by farmers should be transparent and proactive in their reach to the farmers in every village and particularly the most vulnerable villages. The local knowledge on adaptation strategies can then be shared on income diversification, floating gardens, duck rearing, constructions of canal and embankment (non-farm labour), etc. (Nargis and Hossain, 2006; Anik et al., 2012).

11.4.3 Thailand

- Farmers do not adopt practices like organic matter incorporation due to lack of immediate returns. A suitable incentive mechanism must be in place to motivate farmers to adopt such practices that will help in enhancing soil fertility and improve the water-holding capacities of soil.
- Farmers perceive that their landholdings are small and the risks associated with new adaptation practices deter them from accepting change. Suitable technology demonstrations on the farmer's field will help in improving farmers' knowledge and help in their decision-making process.
- Development of rice varieties that are flood tolerant with local characters are needed for lowlands.
- The upland villages need drought-tolerant short-duration rice varieties, as well as water-harvesting technologies that will help in increasing supplementary irrigation potential.
- Innovations in alternate sources of income that will help the farmers to diversify their incomes are needed.

11.4.4 Vietnam

- Subsidies to the farmers to better adapt technologies, like improved varieties, etc., will help the resource-poor farmers, particularly the smallholder farmers.
- Farmers feel that fine-tuning the technologies to be location specific will help in better adaptation.
- Farmers do not have access to credit through formal channels because collaterals are a precondition for loans. Access to loans on easy terms and a subsidy on the interest on loans will help the farmers to go for a higher rate of adaptation.
- It is perceived that the smallholder farmers are neglected by the system because they are resource poor and usually are not able to get into the mainstream to be able to afford availing any incentive. Preconditions for availing any type of benefits should be relaxed liberally in the case of smallholder farmers so that they are able to get the necessary help.
- Better training facilities are needed to improve know-how on climate change and adaptation.
- Farmers feel that lower profits and higher risk of crop failures owing to uncertainty in rainfall discourage them from investing in crop production. It will be appropriate to introduce crop insurance schemes and subsidize the premiums of resource-poor smallholder farmers. This will help them in being assured that in the event of a crop failure a minimum return is guaranteed and they will be able to venture into practising better adaptation practices.

11.4.5 China

- Development and introduction of new drought-tolerant varieties and water-saving technologies will help the farmers in better adaptation.
- Developing alternate sources of power and subsidizing it for the farmers will help the farmers in adopting climate-friendly technology.
- Providing water supply and drainage systems, better agricultural machinery on subsidized terms and ecosystem protection methods on state subsidies will also help the farmers.

11.4.6 Africa

- Improved cultivar with drought-tolerant traits.
- Policies and support to move from subsistence to high-input farming.
- Resource conservation measures for long-term sustainability and enhancing livelihood.
- Improved feed and livestock breeds.
- Improved opportunities for diversify farming; access to credits and irrigational facilities.

11.5 Summary and Conclusion

These national and regional micro-level experiences will help to better target vulnerable areas with enhanced climate resilient policies and programmes. The economic, social and environmental dimensions of sustainable development should jointly address the food-security and climate-change challenges. These policies should be addressing the required technical and investment conditions to achieve sustainable agricultural development through an integrated approach that is responsive and adaptable to local conditions.

Notes

1 BRAC, based in Bangladesh, is (as of May 2010) the world's largest non-governmental development organization; Bangladesh Rural Advancement Committee.

2 Grameen Bank is a micro-finance organization and community development bank in Bangladesh that makes small loans to those without collateral.

3 An NGO based in Bangladesh for micro credits; Association for Social Advancement.

References

Adaptation Knowledge Platform (2010) *Scoping Assessment for National Implementation in Thailand*. Regional Climate Change Adaptation Knowledge Platform for Asia, Bankok, Thailand, p. 36.

Anik, S.I., Sayed, M.A. and Khan, A. (2012) Climate change adaptation through local knowledge in the north eastern region of Bangladesh. *Mitigation and Adaptation Strategies for Global Change*, 17, 879–896. DOI: 10.1007/s11027-011-9350-6.

Khatun, F. and Nazrul Islam, A.K.M. (2010) *Policy Agenda for Addressing Climate Change in Bangladesh: Copenhagen and Beyond*. CPD Occasional Paper No. 88, Centre for Policy Dialogue, Dhaka.

Nargis, N. and Hossain, M. (2006) Income dynamics and pathways out of rural poverty in Bangladesh, 1988–2004. *Agricultural Economics* 35, 425–435.

Shiferaw, B.A., Okello, J. and Reddy, R.V. (2009) Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. *Environment, Development and Sustainability* 11, 601–619.

Wossen, T., Berger, T., Swamikannu, N. and Ramilan, T. (2014) Climate variability, consumption risk and poverty in semi-arid northern Ghana: adaptation options for poor farm households. *Environmental Development*, 12. pp. 2–15. Available at: http://dx.doi.org/10.1016/j.envdev.2014.07.003.

12 Way Forward – Towards Climate Resilience

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Abstract

This chapter sketches out the intervention needs from the evidence evolved from the comprehensive analysis described in the previous chapters. The authors argue that there are innumerable entry points for interventions that should be in place through policies, and programmes to create an enabling environment to adapt effectively among the rural population in the arid and semi-arid tropics. This chapter summarizes the critical areas identified within the sustainable livelihood framework that has to be promoted relentlessly until the very objective of enhancing resilience is achieved. The current policies and support are blanket in nature and they resonate a high disconnect because they are aggregative, top down, highly macro-level approaches. Furthermore, they are often coupled with uncertainties and information gaps, thereby vitiating the mainstreaming of adaptation options that is crucial for these marginal environments of the developing world. A comprehensive policy recommendation will be discussed with reference to contexts of Asia and Africa.

12.1 Introduction

Environmental issues are increasingly acquiring global recognition with more emphasis on strategies to minimize impacts resulting from a changing agricultural production environment. Strategies are identified to aid towards sustainable and efficient production to meet the increased demand of food production, thereby sustaining the livelihood of the population that depend on it. Through several approaches and analysis, we gain an understanding of the relative impact of changing climate on rural life in the semi-arid tropical environment in Asia. Ensuring sufficient food for the ever-increasing global population through improved productivity and increased resource use efficiency continues to be a key challenge in this century. Since the competition for natural resources like water and land is increasing, compounded by the challenge of climate change and associated variability of weather and its impact on agriculture, the challenge appears to be even more daunting (Shiferaw and Bantilan, 2004). The global community must produce more using fewer natural resources under uncertain climate conditions in agriculture. Agriculture production systems are also to be environment friendly by reducing carbon emissions. Indeed this is a daunting task. To achieve this task of paving the way for a 'climate smart agriculture', several measures must be taken, including putting policies, institutions and infrastructure in place, and making farm communities better informed and empowered with necessary resources. As a response to the impacts of

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climatic extremes and the initiatives to tackle the expected impacts, countries have come up with strategies and plans, e.g. India (NAPCC, 2008; NATCOM, 2009), Bangladesh (NAPA, 2005; BCCSAP, 2009), Sri Lanka (NATCOM, 2000; NCCASS, 2010), Thailand (MONRE, 2008b), Vietnam (MONRE, 2008a) and China (NCCP, 2007). These strategies and plans are not properly oriented, however, to cater to the regional or local specific needs. These programmes may be implemented with a downstream approach to have maximum response where the targeted stakeholders receive maximum benefits (Table 12.1).

The Asian Development Bank (ADB)-funded project on 'Vulnerability to Climate Change: Adaptation Strategies and Layers of Resilience' builds its strength from the grassroots and a need-based approach that it has followed in providing science-based solutions and pro-poor approaches for adaptation of agricultural systems to climate change for the most vulnerable people in semi-arid regions of Asia. The project had envisioned the identification and prioritization of the

Table 12.1. National initiatives on building climate change resilience.

Country	Initiatives
Bangladesh	Submitted the initial national communication in 2002 to UNFCCC.[1] The national climate change strategy and action plan was drafted in 2008. It constitutes (i) food security, social protection and health; (ii) comprehensive disaster management; (iii) infrastructure; (iv) research and knowledge management; (v) mitigation and low carbon development; (vi) capacity building and institutional strengthening. National Plan for Disaster Management released in 2010.
India	Submitted first national communication to UNFCCC in 2004 and second national communication in 2012. National action plan on climate change (NAPCC) was released in 2008. It identifies eight missions in the areas of solar energy, enhanced energy efficiency, sustainable agriculture, sustainable habitat, water, Himalayan ecosystem, increasing forest cover and strategic knowledge on climate change. The Indian Council for Agricultural Research (ICAR) has launched a major project entitled National Initiative on Climate Resilient Agriculture (NICRA) during 2010–2011 in the 11th national plan in conjunction with the proposed NAPCC. To achieve coherence between strategies and action at national and state level: state-level action plans on climate change (SAPCC) were drafted to address existing and future climate risks and vulnerability. Out of 28 states, 14 have drafted an SAPCC and further planning is underway towards implementation.
People's Republic of China (PRC)	Initial national communication to UNFCCC was submitted in 2004. The country issued a national action plan to address climate change in 2007.
Sri Lanka	Submitted first national communication in 2000 and second in 2012 to UNFCCC. In 2010, a National Climate Change Adaptation Strategy for Sri Lanka (2011 to 2016) was drafted with a definite framework for action.
Thailand	Submitted first national communication in 2000 and second in 2011 to UNFCCC. In 2008, Thailand's strategic plan on climate change released underlying the proposal of six strategies to tackle climate change. Capacity building, promoting greenhouse gas (GHG) mitigation activities, supporting research and development, raising awareness and public participation, building research capacity, supporting international cooperation are the strategies drafted to address its impacts.
Vietnam	Submitted first national communication in 2003 and second in 2010 to UNFCCC. The national action plan on climate change (2012–2020) was approved in 2012.

sectors most at risk and development of gender equitable agricultural adaptation and mitigation strategies including 'best fit' technologies as an integral part of agricultural development in the most vulnerable areas (Smit and Pilifosova, 2001). The climate characteristics were studied in detail, vulnerable regions identified and farmers' responses were elicited from villagers. It is essential that the future needs of the farmers in Asia – to successfully implement adaptation measures against climate change/variability and to improve agricultural productivity and incomes of the farmers – be addressed.

The primary focus of the study was to look at the farmers' adaptation strategies against climatic variability. On the basis of the evidence and understanding of the farmers, traditional and current adaptation strategies against weather variability were identified. The report attempted to document some indicative possibilities to substantiate the global agenda on climate change. Current policies are resonating a disconnect because they are aggregative, top down, highly macro-level studies. They are often coupled with uncertainties and information gaps, thereby vitiating or obstructing the adaptation or mainstream into the policies/programmes affecting the marginal environments in the developing world.

The sets of recommendations which emerged from the studies resulted in the need for stakeholder consultation, policy dialogues and meeting of minds in this cross-country project. It is envisaged that the above issues centric to the agenda of climate change challenges in the marginal

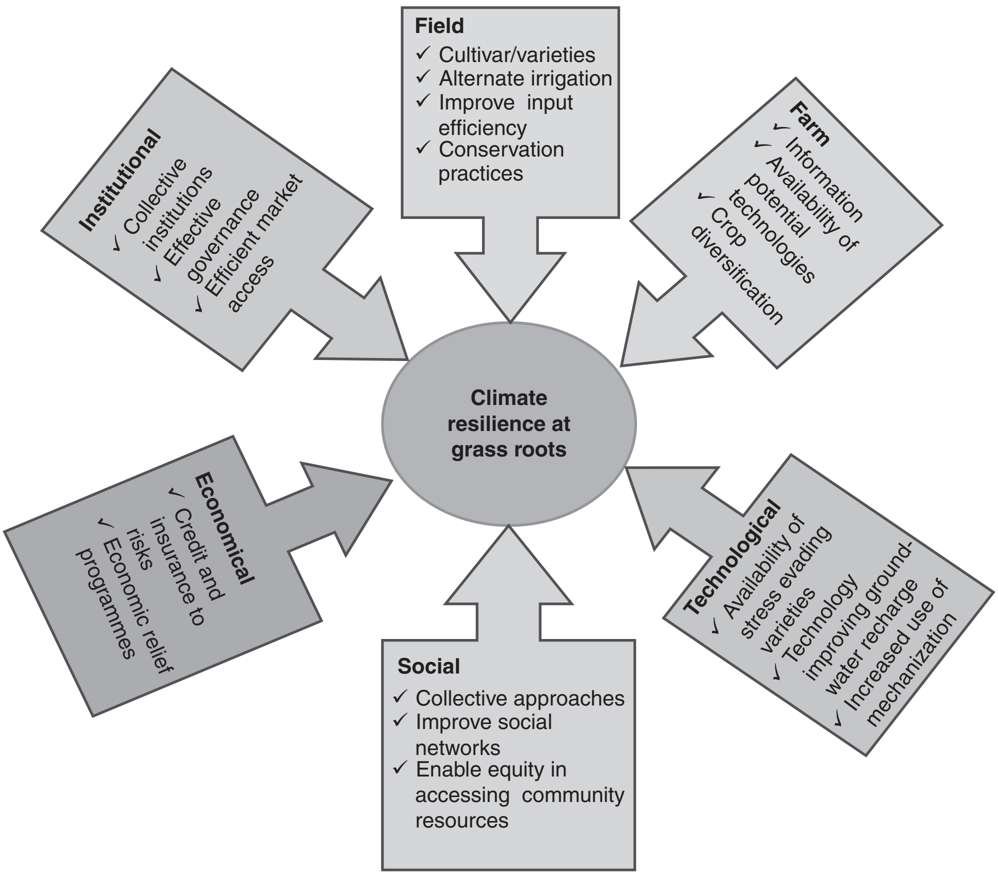

Fig. 12.1. Actions recommended to enhance climatic resilience at the grass-roots level in Asia.

regions of Asia and Africa will be addressed well by providing suggestions on strategies and policies to reduce the vulnerability, strengthen adaptive capacity and opportunities, and provide options to the farmers to cope better with the impending climate change. The experience from these studies advocated the flexibility in approaches that are need based. There are several components to be integrated at grass-roots that need to be strengthened. Even though the factors in each component are location specific, identifying and giving considerable support in strengthening is important (Fig. 12.1). This mainstreaming should go beyond integration and identification of weaker links.

The project has successfully collected and analysed primary data from 22 villages from six countries across Asia along with secondary data to understand climatic variability, farmers' perceptions and vulnerability to climate change. Keeping in view the results and future needs of the farmers in these countries to successfully implement the adaptation measures to address climate change and improve agriculture productivity and incomes, certain strategic measures are to be in place. An attempt was made to pull together all the necessary aspects for action to achieve the above goal. The set of actions were grouped under different categories: (i) policies and strategies; (ii) tools and technologies; (iii) financing for transformational change; and (iv) partnerships for smart agriculture. The following list is indicative and is neither exhaustive nor specific. The idea is to suggest policies/strategies to create an enabling environment for the farmers in South and South-east Asia to address climate variability and also to address socio-economic problems resulting from changing weather patterns.

12.2 Policies and Strategies to Minimize Climate Change Impacts for a 'Climate Smart Agriculture'

It is very important that all the initiatives that are considered to address adaptation and mitigation to climate change must be integrated with government policies that address agriculture, food production (Klein *et al*. 2005) and livelihood. This will ensure effective mainstreaming. The measures identified should be sustainable based on location specificity and adaptation gains.

Integration of climate change initiatives (such as NAPAs,[2] NAPCC,[3] NICRA[4], NDMA,[5]etc.) with the national agricultural policies/programmes (food security, disaster management, natural resource conservation technology adoption, livelihood enhancement, etc.) to encourage rural communities to concede to proposed adaptation measures to address climate change impacts.

Response to climatic shock may not be good, but it is important to identify these responses and work towards improving their capacity to be adopted during the time of climatic emergencies (Eriksen *et al*., 2011). There is a need to implement measures that will enable the farmers to invest in adaptation measures (e.g. short-duration varieties, soil and water conservation technologies, crop management practices, replenishing the feed and fodder management, etc.) to mitigate the negative climate change effects. An example could be to encourage farmers by providing subsidies on interest on loans for implementing adaptation measures. Subsidies on weather-based crop insurance could be a measure to tackle the climate risks associated with extreme weather events. Development of strong collective initiatives such as co-operative movements will improve economic status and help in facing climate shocks.

Prioritizing regions of climate change vulnerability in arid and semi-arid tropics; preparation and implementation of comprehensive district-wise (local level) agriculture and livelihood contingency plans[6] of actions for effectively managing the climate risk.

From meso-level data analysis, the regions vulnerable to long-term climate change need to be identified. Regional crop-contingency plans, i.e. district-wise, will be a response to anticipated climate change developed on an annual basis, with sufficient flexibility. In all study countries, regional-level plans exist and identifying vulnerable sectors and regions is a pre-requisite. (For example in Vietnam a master plan in response to climate change in Ninh Thuan and Ninh Phuoc district was drafted with rounds of revision and prioritization exercises).

Encourage crop and livelihood diversification[7] and ensure rural income flow; managing the common property resources (ponds, wells, tanks, grazing land, etc.) judiciously by community participation enabling long-term sustainability.

Increasing dry spells in the wet seasons, delayed monsoons and other climate-change-related effects require tailoring a location-specific cropping calendar and developing suitable crop management techniques through research and interaction with the farmers.

The farming income is not considered sufficient to cover the increasing risks from uncertainty and variability in rainfall and occurrences of extreme events such as droughts, floods, etc. Farmers are increasingly looking for diversification to high-value crops and other income-generating enterprises from traditional agriculture to cushion the risk associated with agricultural production and income loss. Farmers need an enabling environment that creates or assists in innovation by the farmers to diversify their income sources. This could be achieved through rural developmental agencies. Hence, revamping of rural developmental agencies such as SFDA[8] and DRDA[9] focused towards small farmers in India, policies on sustainable development,[10] livestock production,[11] irrigation[12] and fisheries and aqua-cultural development, etc. in Vietnam and its programmes is a must in all the countries of study. In India, evoking the focus of these rural development agencies to farm and non-farm evenly is a must.

Support to implement pasture conservation and better feed and fodder management[13] approaches for improved productivity of livestock, fisheries, poultry and other enterprises.

There is a need to improve feed and fodder management to enhance fodder quality and availability to improve livestock productivity. Cereal-based systems, particularly coarse cereals, are slowly being replaced with other cash crops in villages in India, China, Bangladesh, Thailand, Sri Lanka and Vietnam. As a result, the availability of dry fodder to feed the livestock population has become an issue. Options for improved fodder management and availability will ensure a healthy development of the livestock sector in the villages for the farmers to diversify their income options. There are several state/district/national level livestock/poultry/fisheries programmes officially being implemented in the region; however, the time has come to re-examine the impacts of these programmes and policies on livelihood and ensure better effectiveness and efficiency.

Ensure equitable access of government support/relief programmes such as the Antyodaya[14] programme, food security programmes in India, and the VGF[15] programme, CIP, etc. in Bangladesh.[16] These programmes focus on food security, agricultural and enterprise subsidies, rural finances, poverty reduction programmes, technology adoption support, etc.

All groups of farmers must be able to get loans under easy conditions. This will enable small and disadvantaged farmers to implement adaptation measures to address climate change. This is true only if there is no recurrence of drought in this period. In reality droughts recur in this timespan and many of these farmers fall into perpetual debt traps. Access to finance on easy terms and highly subsidized interest will help them come out of the debts.

Support in terms of subsidies must be given for choosing adaptation measures and innovative technologies to address climate-change impacts as well as productivity-improving measures of watersheds, integrated water and nutrient management options for efficient use of resources such as land, water, etc., as well as any other inputs. This is mainly because farmers in vulnerable areas do not have any social safety nets and require support to sustain and continue crop production. Easy access to support mechanisms like government interventions in terms of knowledge flow and/or financing options might help.

Strengthen and empower the final beneficiary, i.e. farmers, to make them meaningful partners. Supplement their traditional/experiential knowledge with valid scientific know-how and technology options, engage them more meaningfully in climate information management systems, provide incentives to farmers to adopt natural resource conservation measures and support to improve the existing indigenous technologies that are eco-friendly.

Although the farmers had a wealth of information and experience in dealing with climate-change variability and the harsh realities of moisture stress, they were still lacking knowledge on accessing information and taking the optimum use of services provided by the governments. Often they are unaware of their entitlements, reliefs on offer and other government support programmes and thus fall prey to ignorance and consequences of extreme climate conditions. In vulnerable areas, farmers also lacked social capital and the organizational capabilities. They are often passive suppliers of information to the state and research establishments, but not integrated as valuable and active stakeholders in the climate change debates or intervention programmes. The concept of 'climate change schools' could have sufficient potential for sharing information and knowledge (indigenous knowledge), etc. The weather data collected at local levels once synthesized centrally must go back to the farmers as useful outputs so that they can and are assisted to make effective use of inferences drawn. The study also calls for a strengthening extension programme and institutionalizing an effective mechanism of information dissemination through the Agricultural Technology Centre (KVK,[17] ATMAs[18] in India) in every block/mandal/sub-country level.

Prioritize investment in training officials, extension and local development workers to make them more effective change agents in assisting farmers and strengthening institutions to improve climate adaptation capacity at local levels.

Officials responsible for the farmers' socio-economic well-being may be educated in climate change and mitigation through a series of awareness programmes. Such programmes may be conducted at the village level and the required incentives need to be provided. To illustrate, it is observed that Common Property Resources (CPRs) like grazing lands have degraded over the past several decades owing to lack of collective action in managing them. It will be appropriate for extension officials to educate the farmers on low moisture availability in their ecosystem and the way to mitigate the problem. It is necessary to emphasize capacity building for the government employees dealing with farmers' problems in particular and agriculture in general. The lack of needed competitiveness in understanding climate-change-related implications and experience is highly recommended for all the partner countries, particularly for Vietnam and Thailand. Moreover, various stakeholders involved in nation building through agriculture development are not well aware of global policies, decisions and other related information.

12.3 Tools, Technologies and Infrastructure for 'Climate Smart Agriculture'

Increasing the density of weather observatories; establishing rain gauges at village level; enabling access and efficient management of weather-related information (remote sensing and GIS) and repositories.

Weather, especially rainfall, is variable across the regions. Analysis of single station data may not represent the accurate climate conditions. Micro-level weather data analysis using micro-level data showed a decreasing trend in the rainfall compared to the positive trends at a district level. This feature was observed in two selective project locations in India and Thailand. Village-level rainfall observations are important in characterizing the environment at the micro-level. There is therefore a need to increase the density of network of weather stations for better interpretation of variability of weather parameters and for accurate planning for improved and sustainable agricultural production.

Typhoons and flash floods as well as drought events are common in the Asian countries. In the event of increased frequencies of extreme weather events, agricultural production gets affected considerably. The best way to reduce the impact is to prepare the farmer well in advance to manage the situation in order to minimize the losses. Weather-based agro-advisories benefit the farming community in ensuring effective agricultural operations. In spite of best efforts to alert the farmers, extreme weather events often cause huge losses, subjecting the farmer to extreme hardships. To save the farmer from the weather hazards, weather insurance is quite beneficial. To cope with disasters such as typhoons, flash floods or droughts, the identification of geographical boundaries for such events followed by the preparation of regional crop-contingency plans must be put in place. These will form ‘ready-reckoners’ to meet any eventuality. They should be prepared to deal with the year-to-year variability. Modern tools such as remote sensing and geographic information systems (GIS) should provide an excellent opportunity to analyse spatial land-use and land-cover changes in response to climate change. There have been initiatives[19] from the government on this front in the study countries to improve the infrastructure and database on climate information and to use advanced methods.

Institutionalize continuous mechanisms to collect and collate micro-level information (climate, crops, socio-economic, natural resources, etc.) and efficiently transmit them to be used in formalizing macro-level policies.

Most of the macro-level policies are formulated with inputs from an aggregated level. The aggregated information and existing micro-level information could be highly diverse. There is a pressing need to have micro-level information on climate, crops, socio-economics, natural resources, governance, trends and efficiencies, etc., especially in the context of climate-change issues. Micro-level information needs to be collected and collated to be accessed and used by various national/regional, governmental/non-governmental and other developmental agencies for efficient planning.

Blending of farmers’ traditional/indigenous knowledge on resource conservation, coping strategies, etc., and with advanced technological interventions (varieties, crop management, community resource conservation, rainwater harvesting and storage, etc.) for coping with climate change and associated stress.

Farmers have inherited the knowledge of managing and understanding the climate through their ancestors. Hence, there is a need to utilize this ancient wisdom[20] along with modern know-how. For effective utilization of modern technologies, combining traditional knowledge may improve reliability and acceptability.

Encourage investment in research and development of locally adaptable crops, management practices, input sources, decision support systems (DSS) and models for analysing the impacts of climate change and mitigation strategies in the semi-arid tropics in view of future climate scenarios.

With the changes and increasing variability of weather patterns, and introduction of new crops and varieties, the pest and disease behaviour is likely to be altered in any given location. There is a need to identify such location- and crop-specific pest and disease incidence and approaches to manage such situations developed. For example, in Maharashtra (India), the introduction of sugarcane in Shirapur and soybean in Kanzara and improved and short-duration pigeonpea in Kalman villages brought in new diseases and pests that needed different management practices from the norm. Improved on-farm water harvesting and water conservation measures are useful in rainfed agriculture; similarly, improved technologies like drip irrigation and precision timing of irrigation will reduce the risk associated with the variability of rainfall (Barron *et al*., 2010; Lundqvist and Falkenmark, 2010; Rockström *et al*., 2010).

Incorporating organic matter or mulching to increase the water-holding capacity of soils, and *in situ* water storage using different devices are time-tested measures adopted by farmers such as cover cropping, mulching, composting, etc. The different techniques adopted by farmers in the region provide an array of options for field validation in other countries and subsequent adoption.

Encourage adoption of location-specific conservation techniques (cover cropping, in situ *moisture conservation, rainwater harvesting, groundwater recharge techniques, locally adapted cropping mixtures, etc.) for water-efficient agriculture and demonstration of these available technologies*[21] *in the farmers' field.*

Incentives or support must be given for choosing adaptation measures and innovative technologies to address climate-change impacts as well as productivity-improving measures for efficient use of resources such as land, water etc., as well as any other inputs. For example, modern technology and external support by government in India and also non-government organizations in Sri Lanka and Bangladesh helped the farmers in many villages to harvest groundwater through agro wells and tube wells. In recent decades there has been a rapid, uncontrolled expansion in the number of tube wells in many villages, resulting in receding of the groundwater table. Such 'tragedy of the commons' should be avoided through collective action, regulation by external agencies or systems of incentives and disincentives. The groundwater situation is sometimes aggravated by the low level of education of farmers. This acts as a barrier to preventing over-harvesting of groundwater, as practised in Ninh Thuan province in Thailand. Thus, improving the knowledge of farmers may be a first step before adopting other measures. There is therefore a call for sensitivity to local socio-economic contexts when addressing mitigatory measures.

Managing climate risks effectively through weather-based agro-advisories, and developing equally accessible innovative weather insurance products.[22]

In the event of increased frequencies of extreme weather events, agricultural production gets affected considerably. The best way to reduce the impact is to prepare the farmer well in advance to manage the situation in order to minimize the losses. Weather-based agro-advisories can really benefit the farming community on timely agricultural operations. In spite of the best efforts to alert the farmers, extreme weather events often cause huge losses, subjecting the farmer to extreme hardships, and weather insurance can be an effective strategy to offset the losses. In order to prepare the weather insurance products for different agroclimatic regions, research efforts on crop-weather relations need to be strengthened.

Harnessing non-conventional energy[23] *sources in agriculture and other allied sectors*

The use of non-conventional sources of energy, such as bio-fuels, solar energy and wind power, in agricultural operations is very limited; where there are more effective state interventions, such as in China, successful interventions in the rural areas have been possible, with high levels of adoption. In order to reduce the GHG emissions from different sources, more research is required to estimate the emission levels and instigate measures to restore the balance.

12.4 Financing and Partnerships for Transformational Change

Enabling an environment to attract public and private finances to invest in 'Climate Smart Agriculture'.

Increasing the level of state financing for promoting climate smart agriculture is a priority, considering the long-term goals of minimizing food insecurity, reducing carbon emissions and mitigating climate change effects. Public investment in the field of agriculture research and development must be increased. The focus should be to invest in tools and technologies as well as policies. For example, the National Initiative for Climate Resilient Agriculture (NICRA) is a major research and capacity-building national project launched by the Government of India and ICAR to develop location-specific tools and technologies.

Encouraging the role of the non-governmental organizations, and public and philanthropic organizations in enhancing adaptation readiness among the local community.

Along with the government efforts, non-governmental organizations (NGOs) are also important for the development of the rural community. For example in Thailand, Oxfam has undertaken some work on climate change adaptation with local communities in Yasothan province and in BRAC in Bangladesh. There is a need to generate partnerships between public funding and financing from foundations and charitable private institutions for investment into smart agriculture promotion (Vogel *et al*., 2007; Vermeulen *et al*., 2012). Many NGOs and other research organizations funded by various societies and trusts have been doing a commendable job in various sectors. Their involvement in conducting research to manage climate change threats should be encouraged and an enabling environment must be created.

Forging international/regional partnerships for developing tools and technologies adaptable to suit local requirements through pooling finance and intellectual resources.

International partnerships among neighbouring countries that share similar ecosystems as well as similar agricultural practices might be useful in sharing financial and intellectual resources to develop appropriate tools and technologies.[24] The technologies generated at various locations in the world may be collected and identified for their suitability to other regions. The SAARC[25] is a potential platform for cooperation and exchange of tools, technologies, skills, finance and other related resources to combat climate change and enhancing resilience in South Asia. Similar platforms could be set up in South-east Asia and China.

12.5 Summary and Conclusion

Through these project initiatives, we identified a list of significant factors that are crucial in carrying out micro-level studies on vulnerability and resilience to climate change. The identified factors from the study are:

- A dire need for collection, analysis and dissemination of reliable information on climate response related variables (including farmers' perceptions) in diverse micro-level spatial contexts.
- The preparation of area-specific inventories of indicative production and resource use options (possibilities) for dryland agriculture to match with the opportunities and constraints.
- The search for indicative adaptation options (Fraser, 2007) for the above inventory should focus on: (i) prevailing

farmers' practices in different areas with varying degrees of vulnerability (e.g. water scarcity or aridity) and other environmental constraints; (ii) agricultural R&D and location-specific scientific results; and (iii) formal and informal institutions and support systems including infrastructural changes with specific focus on success stories and visible failures.

- The first three factors above should help in building an inventory of multiple and diverse options out of which farmers would have the flexibility to choose and use depending on the varying climatic conditions in their micro-level contexts.

The overarching suggestions help to diagnose and understand farmers' adaptation strategies against climate variability with a focus on the dynamics of adaptations, and improving resilience to change. This will enable the government to: (i) create a conducive environment for the farmers to absorb adaptation strategies; (ii) develop technological inputs and tools as appropriate adaptation measures; (iii) create and strengthen the existing institutional infrastructure to assist the farmers towards an equitable adaptive capacity; and (iv) streamline the governance structures to smooth the flow of information and resources to the farmers and be responsive to their needs.

The implementation of the above all-encompassing suggestions highlighting dynamism, diversity and flexibility would need both enhancement and reorientation of the capacities of the farmers and rural communities, as well as the institutional arrangements and innovations supporting them. There should also be an effort directed at strengthening collective actions and formal and informal networks to ensure equity (Rodima-Taylor, 2011; Rodima-Taylor *et al.*, 2011). Stemming from the grass-roots and need-based approach, the study elicited the farmers' perception and practices, their natural resource base, current and potential adaptation practices in the form of adjustment in their farming and non-farming systems and practices. In order to ameliorate the local-level constraints, strategies to respond to climate change/variability must be mainstreamed into the development agendas of all countries keeping the following aspects in mind.

To sum up from the lessons learned from the exercise: (i) adaptation strategies should incorporate diversification as a key element in terms of interventions as well as systemic support – local-level efforts (horizontal) at information management and institutional coordination as well as working with national-level bodies and aggregates (vertical); (ii) since income sources, options, and opportunities to adapt are increasingly recognized as vital, adaptation strategies must to have a strong dynamic orientation, thus recognized as requiring continuous change; (iii) in keeping with the emerging evidence on convergence between development and adaptation processes, adaptation should be an integral part of development strategies;[26] (iv) the requisite space for a grass-root-level understanding of adaptation strategies helps in better and pragmatic bottom-up approaches (an understanding reinforced by details from field studies, e.g. ICRISAT VLS panel data); (v) for adaptations to be effective not only calls for individual household-level understanding and capacities, but a strong element of collective action and institutional support on the one hand and proactive approach of the formal public and private agencies on the other; (vi) the conservation of community resources should be encouraged through appropriate support and by imparting timely awareness and logistics to enhance adaptation; and (vii) finally, the development policies for diverse agro-climatic regions need to have explicit and effective support for integrated adaptation strategies. The purpose of this study is also to inform of and induce the same.

Notes

1 United Nations Framework Convention on Climate Change; parties to the Convention must submit national reports (national communication) on national circumstances and other details on the implementation of the Convention to

the Conference of the Parties (COP).

[2] National Adaptation Programs of Action identify priority activities that respond to their urgent and immediate needs to climate change by which further delay would increase vulnerability and/or costs in the future.

[3] National Action Plan on Climate Change.

[4] National Initiatives for Climate Resilient Agriculture.

[5] National Disaster Management Authority.

[6] Includes state/district level contingency plans, disaster management plans and other reliefs.

[7] Enable opportunities to diversify more into high-value crops, livestock and other non-farm income sources.

[8] Small Farmer Development Agency.

[9] District-level Rural Development Agency.

[10] Decision No 153/2004/QD-TTg, on Direction of Sustainable Development in Vietnam.

[11] Decision No 10/2008/QD-TTg on Strategy of Livestock Production Development up to 2020.

[12] Decision No 1590/QD-TTg on Strategy of Irrigation Development up to 2020.

[13] This concerns programmes/schemes on dairy development; development of small ruminants; fodder and feed development; livestock entrepreneur programmes, etc. In India, the concerns of demand for fodder and pasture are on with 12th plan call for rehabilitation of pasture and fodder resource in the country. This involves the national livestock development board and other public livestock enterprises in Sri Lanka.

[14] Schemes under the programme included land allotment, agriculture and land development, animal husbandry, village and cottage industries, wage employment, old-age pension and housing subsidy, etc.

[15] Vulnerable Group Feeding program

[16] Government of Bangladesh's country investment plan (CIP). This CIP has identified six focus areas to continue their effort to achieve the Millennium Development Goals (MDGs).

[17] Krishi Vigyan Kendra' is a district-level institution engaged in transfer of latest agricultural technologies to the end users for bridging the gap between production and productivity.

[18] Agricultural Technology Management Agencies addressing the constraints faced by the extension system.

[19] In India, the Indian Meteorological Department (IMD) and allied departments are greatly involved in enhancing weather information by improving weather station density across the country.

[20] On weather prediction, water conservation and storage, cultivation practices, namely organic farming, natural pesticides, etc.

[21] Support in soil and water conservation, soil health, irrigation, fertilizer, etc.

[22] Weather-based insurance schemes; government support through subsidies on premium. When weather indices differ from the guaranteed indices of major crops, a payment equal to the deviation/shortfall is payable to all insured farmers.

[23] There is progress in the initiatives by the respective governments. These are well highlighted in the related policies and strategies, national action plans, etc.

[24] Drought-, flood- and salt-tolerant varieties, robust methodologies to predict climate change impacts, resource conservation technologies, innovative safety nets, etc.

[25] South Asian Association for Regional Cooperation (SAARC) has an objective of providing the promotion of economic and social progress, and cultural development within the South Asia region.

[26] Suggested by Halsnaes and Verhagen (2007).

References

Barron, J., Enfors, E., Cambridge, H. and Moustapha, A. (2010) Coping with rainfall variability in semi-arid agro-ecosystems: implications on catchment scale water balances by dry spell mitigation strategies among small-scale farmers in Niger. *International Journal of Water Resources Development* 26, 543–559.

BCCSAP (2009) *Bangladesh Climate Change Strategy and Action Plan 2009*. Ministry of Environment and Forests, Government of Bangladesh (GoB).

Eriksen, S., Aldunce, P., Bahinipati, C.S., D'Almeida, T., Molefe, J.I., *et al*. (2011) When not every response to climate change is a good one: identifying principles for sustainable adaptation. *Climate and Development* 3, 7–20.

Fraser, E.D.G. (2007) Travelling in antique lands: using past famines to develop an adaptability/resilience framework to identify food systems vulnerable to climate change. *Climatic Change* 83, 495–514.

Halsnaes, K., and Verhagen, J. (2007) Development-based climate change adaptation and mitigation-conceptual issues and lessons learned in studies in developing countries. *Mitigation and Adaptation Strategies for Global Change* 12, 665–684.

Klein, R.J.T., Schipper, L.E.F. and Dessai, S. (2005) Integrating mitigation and adaptation into climate and development policy: three research questions. *Environmental Science and Policy* 8, 579–588.

Lundqvist, J. and Falkenmark, M. (2010) Adaptation to rainfall variability and unpredictability: New dimensions of old challenges and opportunities. *Water Resources Development* 26, 595–612.

MONRE (2008a) *National Target Program to Respond to Climate Change*. Government of Vietnam, p. 111.

MONRE (2008b) *Thailand's Strategic Plan on Climate Change*. Government of Thailand.

NAPA (2005) *National Adaptation Programme of Action (NAPA)*. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh (GOB). Dhaka.

NAPCC (2008) *National Action Plan on Climate Change*. Government of India, Prime minister's council on climate change. p. 59. http://www.moef.nic.in/sites/default/files/Pg01-52_2.pdf (Accessed 12 July 2015).

NATCOM (2000) *Initial National Communication under the United Nations Framework Convention on Climate Change, Sri Lanka*. Ministry of Forestry and Environment, Colombo.

NATCOM (2009) *India's National Communication to UNFCCC. Data Extraction tool for Regional Climate Scenario (PRECIS) for India*. Ministry of Environment and Forests, Government of India.

NCCASS (2010) National climate change adaptation strategy for Sri Lanka 2011–2016. *Strengthening Capacity for Climate Change Adaptation*. Climate Change Secretariat. Ministry of Environment. Government of Sri Lanka.

NCCP (2007) *China's National Climate Change Programme*. National Development and Reform Commission. People's Republic of China.

Rockström, J., Karlberg, O., Wani, S.P., Barron, J., Hatibu, N., *et al*. (2010) Managing water in rainfed agriculture – the need for a paradigm shift. *Agricultural Water Management* 97, 543–550.

Rodima-Taylor, D. (2011) Social innovation and climate adaptation: local collective action in diversifying Tanzania. *Applied Geography* 1–7.

Rodima-Taylor, D., Olwig, M.F. and Chhetri, N. (2011) Adaptation as innovation, innovation as adaptation: an institutional approach to climate change. *Applied Geography* 1–5.

Shiferaw, B. and Bantilan, M.C.S. (2004) Agriculture, rural poverty and natural resource management in less favored environments: revisiting challenges and conceptual issues. *Food, Agriculture & Environment* 2, 328–339.

Smit, B. and Pilifosova, O. (2001) Adaptation to climate change in the context of sustainable development and equity. *Contribution of the Working Group to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, pp. 879–912.

Vermeulen, S., Zougmore, R., Wollenberg, E., Thornton, P., Nelson, G., *et al*. (2012) Climate change, agriculture and food security: a global partnership to link research and action for low-income agricultural producers and consumers. *Current Opinion in Environmental Sustainability* 4, 128–133.

Vogel, C., Moser, S.C., Kasperson, R.E. and Dabelko, G.D. (2007) Linking vulnerability, adaptation, and resilience science to practice: pathways, players, and partnerships. *Global Environmental Change* 17, 349–364.

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