Agricultural Adaptation and Climate Change Policy for Crop Production in Africa

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Abstract Africa is considered among the most highly vulnerable regions to climate change because of extremes of drought, flooding, inappropriate land tenure systems, overdependence on rainfed agriculture, and widespread poverty. The impact of climate change is moderated by several factors such as access to land, inputs, credit, and markets. Thus, there is a critical need for decision makers at different levels in Africa to develop matching response strategies and policies to reduce vulnerability and foster resilient livelihood systems on a sustainable basis. The smallholder farming communities are inherently the most vulnerable to the negative impacts of climate change, and are always away from the advantage of any emerging opportunities due to resource constraints. About 65 % of national agricultural earnings in this continent is derived from the crop production of staple cereals, particularly maize. Due to shrinkage in cultivated area, production is also about 5–25 %, and the region's need is more chronic for food and feed. The climate change challenge is aggravated by diminishing soil productivity and the decline in natural resources has affected the livelihood of rural and peri-urban communities. The communities have drawn on their indigenous knowledge systems with the support of local institutions and traditional social safety nets to adopt the various multiple stress factors related to climate change and variability. However, there is still limited empirical evidence on the robustness of these systems in support of social collaborations and resolving conflicts arising from the resource scarcity in the wake of climate change. Comprehensive policy frameworks are therefore required to expand the climate change adaptation horizons beyond the boundaries of current farming systems. For instance, the risk of crop-based enterprises has increased by deteriorating climatic conditions. There is much evidence of multiple stresses characterising the existing poverty traps for the predominantly rural communities, and challenges of chronic food insecurity, but no evidence on how current agriculture and climate change policy frameworks are able to address these multiple stress factors against

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the increasing risk and uncertainty of agriculture as a source of climate change adaptation. Currently, the majority of the farmers lives beyond the reach of markets, yet agricultural development policies are hinged on the principles of market participation. Transformation of these subsistence farms into commercially oriented and market-driven production systems will effectively call for structural and process changes in knowledge systems, technology development and delivery, institutions, and policies.

The empirical research shows evidence of current and future impacts of climate change and variability on agricultural production systems, and their implications on the resilience of smallholder farming systems currently supporting the poorer and more vulnerable communities. Over the past decade, there has been a remarkable increase in awareness about climate change issues with diverse stakeholders, including policy makers. The lack of knowledge on the nature, magnitude, and direction of impacts at the indigenous community and national scales will likely continue to haunt decision-making processes regarding the development of robust strategies and policies to support adaptation. However, the regional agricultural sector has to undergo major transformation processes in order to meet emerging demands for adaptation. This may entail changes in the types and forms of information, knowledge, technologies, resource regimes, and institutions driving current production systems. There are still major knowledge gaps across disciplines on how local-level changes in climatic factors influence the socioecological processes that underpin agricultural production systems across spatial and temporal scales. Thus, it has been concluded that the policy making on climate change in Africa is not necessarily constrained by the lack of empirical evidence, but instead by the failure of policy makers to use available empirical evidence. The current failures in linking research to policy could be a major barrier to further research and development innovations for climate change adaptation. Evidence from limited climate change adaptation studies conducted with communities in the region revealed the importance of policy dialogue platforms as an integral part of research and development initiatives.

Keywords Climate change adaptation • Crop production • Environmental risks • Policy makers • Smallholders

Acronyms and Abbreviations

ACMAD	African Centre of Meteorological Application for Development
ACT	African Conservation Tillage Network
AGRHYMET	Agro-Hydro-Meteorology
APRM	African Peer Review Mechanism
APSIM	Agricultural Production System Simulator
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa

ASWAp	Agriculture Sector Wide Approach of the Government of Malawi
CA	Conservation Agriculture
CAADP	Comprehensive African Development Programme
CCAA	Climate Change Adaptation for Africa
CILSS	Comité permanent Inter-État de Lutte contre la Sécheresse au Sahel
COMESA	Common Market for Eastern and Southern Africa
CORAF/WECARD	Council for Agriculture Research and Development in West and Central Africa
DFID	Department For International Development (UK)
EAC	East African Community
EACCCP	East African Community Climate Change Policy
ECOWAS	Economic Community of West African States
ENDA-TM	Environnement et Développement du Tiers-Monde
FANRPAN	Food, Agriculture and Natural Resources Policy Analysis Network
FAO	Food and Agriculture Organization of United Nations
FARA	Forum for Agricultural Research in Africa
GCOS	Global Climate Observation System
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Green House Gas
GIS	Geographic Information System
ICRAF	World Agroforestry Centre
IDRC	International Development Research Centre
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
IRAD	Institut de Recherche Agricole pour le Developpment (Cameroon)
ISFM	Integrated Soil Fertility Management
IUCN	International Union for the Conservation of Nature
IWMI	International Water Management Institute
LGP	Length of Growth Period
MDG	Millennium Development Goal
NAPA	National Adaptation Programme of Action
NARES	National Agricultural Research and Extension System
NEPAD	New Partnership for Africa's Development
NGO	Nongovernmental Organisation
OECD	Organization for Economic Co-operation and Development
PAR	Participatory Action Research
SADC	South African Development Community
SOFECSA	Soil Fertility Consortium for Southern Africa
UNDP	United Nations Development Programme

UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WAEMU	West African Economic and Monetary Union
WWF	World Wildlife Fund for Nature

1 Introduction

There is much undisputed evidence that shows the climate is changing and there is a lot of uncertainty regarding the pace and extent of the change, and the different impacts on the regions, sectors, nations, and communities. Climate has been a source of threat to agriculture for decades in Africa. With climate change, the continent's vulnerability is increasing, making Africa one of the most exposed regions in the world to climate change (IPCC 2007a). This uncertainty renders policy decision making more complex and magnifies the need for Africa to build its knowledge and analytical base and to strengthen the capacity of country and regional institutions in developing the evidence base needed to address climate change adaptation issues. At present, virtually all countries on the continent have performed some stocktaking of the variability and change in the climate and of the impact of those changes on livelihoods. The least developed countries in Africa have been supported by the United Nations Framework Convention on Climate Change (UNFCCC) to undertake National Adaptation Programmes of Action (NAPAs), and all remaining countries have, to varying degrees, pursued climate change adaptation measures on their own.

This chapter aims to help by identifying gaps in research and policy making for climate change adaptation in the agricultural sector. It further provides information and insights that can be used to bring researchers and policy makers together to improve evidence-based policy making that can enhance food security and protect different categories of populations vulnerable to climate change with respect to the following key questions.

1. What is the role of climate change challenges in the context of the multiple challenges and opportunities facing the agriculture sector in the African region?
2. What is the current state of knowledge on adaptation to climate change in the agricultural sector in the African region?
3. What is the current state of knowledge on whether and how research findings are integrated in agriculture sector policies in the African region?
4. What are the major gaps in research on adaptation to climate change in the agricultural sector?
5. What is needed to ensure that research findings are better integrated into agriculture sector policies?

In the past few decades, there has been growing research interest in and support for adaptation of agriculture to climate change in Africa. The research is called upon to ensure that the findings emerging from relevant field investigations in this domain are actually applied and used to inform policy makers about the necessity of harnessing efforts to make the necessary adaptation to climate change. Therefore, it is highly desirable to make a stocktaking synthesis and to review research results from relevant sources and the way these feed into and influence policies for climate change adaptation in key sectors, particularly the agricultural sector that employs the bulk of the population. It is critical that the concerned ministries in the African countries make policies informed by the existing body of knowledge on climate change, climate variability, and climate change impacts. Results generated by scientific research should, it is hoped, enable the respective sectors to build resilience against climate change and climate variability through adequate adaptation strategies and contribute to mitigation of climate change impacts through the use of improved and innovative technologies and management practices.

2 East Africa

With the change in the climate, the continent's vulnerability is deepening, which has made East Africa the most exposed region in the world regarding the effects of climate change (World Bank 2008). As a result, food and water security, livelihoods, shelter, and health are all at risk. Thus, there is growing research interest in and support for adaptation to climate change in Africa. It is thus imperative that the findings emerging from relevant research are applied and used to inform policy making with regard to climate change adaptation. It is critical that the sector policies are appropriately informed by the existing body of knowledge on climate change and climate variability generated from scientific research. These policies should enable the respective sectors to build resilience against climate change and climate variability through adequate adaptation strategies and contribute to mitigation of climate change through the use of improved and innovative technologies and management practices.

2.1 Overview of Agriculture in the East African Region

2.1.1 State of Knowledge on Climate Change and Impacts on the Agricultural Sector

The African continent is experiencing a general warming trend, with certain regions warming more than others (IPCC 2007a). The warming has been approximately 0.5 °C per century since 1900 (Hulme et al. 2001). Accordingly, temperature projections for East Africa indicate that the median near-surface temperature in the 2080–2099 period will increase by 3–4 °C compared to the 1980–1999 period. It has to be noted that this increase is about 1.5 times the projected global mean response.

Averages of precipitation projections for East Africa, however, quite clearly indicate an increase in rainfall in East Africa for the 2080–2090 period. The changes in precipitation are likely not to be uniform throughout the year, but will occur in sporadic and unpredictable events. It is estimated that the number of extreme wet seasons in East Africa in the 2080–2099 period will increase from about 5 to 20 % (Seitz and Nyangena 2009). It should, however, be noted that precipitation is also highly variable across the continent, although much of the continent has experienced decreases in annual precipitation. An increase in interannual variability has been noted with the indication that extreme precipitation events (floods and droughts) are on the rise (IPCC 2007a). Notwithstanding the inconsistency of predictions about climate change, the effects of the phenomenon are being experienced throughout sub-Saharan Africa, especially in areas typified by variable rainfall shifting growing seasons (IPCC 2001). Most African farmers, particularly those working in rainfed agriculture, have been affected in one way or another.

According to an analysis of countries by NAPA reports, the climate change is expected to increase the frequency and intensity of extreme weather events such as droughts, floods, landslides, and heat waves in the East African region. Despite rigorous and detailed vulnerability and adaptation options not being done in Uganda, the literature review and analysis of empirical information shows that in Uganda the frequency (seven times) of drought has increased between 1991 and 2000 (Government of Uganda 2007).

Climatic projections undertaken for Burundi and Rwanda (Baramburiye et al. 2013; Tenge et al. 2013) suggest that the countries' climate will become warmer (by 1.0–2.5 °C). Furthermore, the CSIRO model projects that temperature increases for the entire country will be in the 1.0–1.5 °C range. Given Burundi's tropical humid climate, this would imply high evaporation–transpiration rates, reducing the water available for plant growth and other uses. Likewise, in Kenya, recent studies that have considered projections of future climate change indicate future increases in mean annual temperature (average monthly temperatures) of broadly 1–3.5 °C over the range of models by the 2050s (2046–2065) (SEI 2009).

Projections of climate change in Tanzania expect a temperature rise of 2.2 °C by 2100, with a high increase (2.6 °C) in June, July, and August. According to meteorological data, monthly temperatures over the past 30 years have shown an upward trend (Government of Tanzania 2007). Although the literature states that rainfall is expected to continue to decrease in inner and dry land regions, coastal areas of Tanzania such as Dar-Es-Salaam are predicted to receive increased rainfall during the rainy season. A detailed account of climate change trends and effects in different sectors including agriculture in Tanzania is presented in its NAPA (Government of Tanzania 2007). Predictions show that the mean daily temperature will rise by 3–5 %. Some areas of northern Tanzania will likely get wetter (by 5–45 %), and others, especially in the south, will likely experience severe reductions in rainfall (up to 10 %). Rainfall is predicted to decrease by up to 20 % in the inner parts of the region and the country, with dry seasons becoming longer and having less rainfall, however, rainfall is predicted to increase by 30–50 % in the coastal areas.

Thus far, all the climate models for the East African region show that rainfall regimes will change, but these changes will vary with season and region. Most models project rainfall will increase on average, although some models project rainfall reductions in some months in some areas. Future predictions on extreme events (floods and droughts) vary much more widely. Many models indicate an intensification of heavy rainfall in the wet seasons, particularly in some regions, and thus greater flood risks. Droughts are likely to continue, but here too the projections are varied: some models project an intensification of these events, particularly in some regions, whereas other models indicate reductions in severity.

The range of models and results highlights a considerable uncertainty in predicting future effects, especially in relation to scenarios of future rainfall, floods, and droughts, although also due to future socioeconomic conditions and environmental services. Nevertheless, the analysis here does reveal potential areas of concern and helps focus priorities. Furthermore, it is essential to recognise this uncertainty, not to ignore it. There is a need to plan robust strategies to prepare for uncertain futures, rather than using uncertainty as a reason for inaction.

2.1.2 Challenges and Opportunities within the Agricultural Sector in the Context of Climate Change

The East African region exhibits considerable climatic and topographic variability. Much spatial and temporal variation in the response of different crops to climate change can thus be anticipated (Thornton et al. 2010). According to Moore et al. (2011), high spatial variability in yield is indicated in several key agricultural subregions of East Africa. It was further established that the broad range of projected crop yields reflects enormous variability in key parameters that underlie regional food security; hence, donor institutions' strategies and investments might benefit from considering the spatial distribution around mean impacts for a given region. Ultimately, global assessments of food security risk would benefit from including regional and local assessments of climate impacts on food production.

In East Africa, climate variability may have devastating impacts on economies. Major droughts typically result in sharp declines in agricultural output along with related productive activity and employment. In turn, this will lead to lower agricultural export earnings and other losses associated with a decline in rural income, and reduced consumption, investment, and destocking (World Bank 1994). Significant droughts also have additional multiplier effects on the monetary economy, the rate of inflation, interest rates, credit availability, levels of savings, government budget deficits, and external debt stocks. Of the top ten disasters in East Africa between 1970 and 2003, nine were caused by droughts (in 1969, 1979, 1980, 1984, 1989, 1990, 1992, 1999, and 2000). The greatest number of people affected by drought was in 1999–2000, totaling 4.4 million people in Kenya alone and about 14.2 million in other EAC countries (World Bank 2007). Many drought periods (1966–1970, 1979–1984, 1990–1992, and 1999–2000) in East Africa have been

Table 1 Major drought years and changes in GDP in the EAC countries

Drought years	Rainfall deficiency (%)	Agricultural GDP loss (%)	Gross GDP loss (%)	Loss in export earnings (%)
1970/1971	15.2	0.50	0.07	17.00
1978/1979	22.0	1.58	1.13	7.98
1980–1983	29.0	27.00	10.00	20.00
1990/1991	10.2	(0.22)	0.43	17.50
1992–1994	11.9	3.64	(1.60)	(9.00)
1999/2000	7.0	11.18	1.44	(8.48)

Adapted from Seitz and Nyangena (2009); figures in brackets are computed from rainfall data and country accounts bulletins

associated with the El Niño Southern Oscillation. Table 1 presents the implications of major droughts on GDP for the countries of the EAC.

Although the potential to invest in irrigation in much of East Africa is high, poor performance of large-scale irrigation schemes in the region and competition for diminishing water resources suggest that smallholder irrigation is preferable. When population grows rapidly, this leads to conflict over natural resources, especially water, which is a limited resource in the first place, given the erratic rainfall, droughts, seasonal shifts, shorter seasons, and dry spells (Liwenga et al. 2012). Climate change and increasing population contribute to water scarcity and limit its availability for irrigation and other productive uses (Turner 2006).

Climate change and variability can impose additional pressures on water availability, water accessibility, and water demand in the East African region. A regional analysis of climate change within the East African region shows that the supply and quality of water will both be affected (Seitz and Nyangena 2009). Changes in the physical and chemical aspects of lakes and rivers, such as higher water temperatures, shorter periods of ice cover, and decreases in river and lake ice thickness have been documented in recent decades. In East African lakes (Edward, Albert, Kivu, Victoria, Tanganyika, and Malawi), deep-water temperatures, which reflect long-term trends, have risen by 0.2–0.7 °C since the early 1900s (IPCC 2007a). Interannual lake-level fluctuations and lake-level volatility have been observed in lakes, including Tanganyika, Victoria, and Turkana since the 1960s. This is probably due to periods of intense drought followed by increases in rainfall and extreme rainfall events in late 1997 (IPCC 2007a).

Despite the fact that the key livelihood activity is agriculture, a recent study examining rainfall, food security, and human mobility in Tanzania indicated that amid an increase in uncertainty in agriculture and high land pressure, nonfarm activities will be the key elements of livelihood strategies for many youths in the future (Liwenga et al. 2012). The findings further established that climate variability causes short- and long-term changes that result in water deficits affecting crop production, and thus influencing decisions to migrate. Accordingly, the preference of the youths has been for migrating to other areas, both rural and urban. Future destinations of migration included cities such as Dar-Es-Salaam, Mwanza, and Arusha.

The migration pattern could be temporal or seasonal depending on the effects of climate-related events such as droughts.

Furthermore, research findings have established that agricultural biodiversity is central to human existence and in particular to climate change adaptation. Farmers, rural communities, and indigenous people around the world maintain the diversity of crops, forage, and tree species, as well as the many other plant, animal, and microbial species found in and around their production areas and depended on to provide food, fuel, medicine, and other products. Climate change, in combination with other drivers, is expected to alter agricultural biodiversity substantially (Chakeredza et al. 2009).

2.2 Climate Adaptation Research in the Agricultural Sector

The adverse impacts of climate change and variability being aggravated by increasing average global temperatures are a threat to the livelihoods of people in almost all sectors of the economy in East Africa. Severe droughts, floods, and extreme weather events, associated with the climatic variability phenomenon of the El Niño Southern Oscillation, are occurring with greater frequency and intensity in the region. This is worsening the state of food security and threatening all the other drivers of economic development. The following section highlights some of the findings based on climate change adaptation research in the agricultural sector in the sub-Saharan region with a specific focus on the East African region.

2.2.1 Vulnerability and Adaptation of Crop-Farming Systems in the Region

Changes in rainfall amounts and seasonal patterns are already being experienced in many parts of the world, including the East African region, creating problems for vulnerable farmers and other land users in securing their livelihoods, and increasing the risks they face. The frequency and intensity of extreme climatic events such as heat waves and erratic heavy rainfall, as well as the long-term chronic effects of higher temperatures, are set to increase (IPCC 2012).

In East Africa, the link between climate and agriculture as the main livelihood activity is very strong. As East Africa depends heavily on rainfed agriculture, rural livelihoods are highly vulnerable to climate variability such as shifts in growing season conditions. Furthermore, agriculture contributes 40 % of the region's GDP and provides a living for 80 % of East Africans (Seitz and Nyangena 2009). In 2003–2004, all East African countries suffered from weather-related food emergencies, and can therefore be considered vulnerable to the impacts of climate change on their agriculture.

The various studies conducted in the East African region indicate that smallholder farmers have observed changes in the amount and distribution of precipitation, associated with increases in temperature (Komba and Muchapondwa 2012). Farmers' responses have generally been using short season and drought-resistant crops, employing irrigation, adjusting planting dates, and planting trees to adapt to the potential negative impacts of climate change on their agricultural yields (Ibid).

Some specific studies and analyses of potential impacts of climate change on crops in East Africa are available. It is reported in Tanzania that in the same farming system, positive and negative impacts may occur on different crops. It is suggested that impacts on maize, the main food crop, will be strongly negative for the Tanzanian smallholder, whereas impacts on coffee and cotton, significant cash crops, may be positive (Agrawala et al. 2003). In Kenya, a 1-m sea-level rise would cause losses of almost US$500 million for three crops (mango, cashew nut, and coconut) (Government of Kenya 2002). In the tea-producing regions of Kenya, a small temperature increase of 1.2 °C and the resulting changes in precipitation, soil moisture, and water irrigation could cause large areas of land that now support tea cultivation to be largely unusable. As Kenya is the world's second largest exporter of tea, and as tea exports account for roughly 25 % of Kenya's export earnings and employ about three million Kenyans (10 % of its population), the economic impact could be tremendous (Simms 2005; WWF 2006). The Ugandan NAPA demonstrates the dramatic impact that a 2 °C temperature rise might have on coffee-growing areas in Uganda. The analysis indicates that most areas could become unsuitable for coffee growing (Government of Uganda 2007).

According to a study on the economics of climate change in East Africa, major rainfall deficient years and the major macro variables show a significant relationship between rainfall amount and GDP (Seitz and Nyangena 2009). Focusing on major drought years, a negative rainfall anomaly, especially one of more than 10 %, brings a loss in agricultural GDP. When the 1999–2000 drought affected an estimated 13.2 m people, destroyed crops, caused deaths of animals, and affected millions of people, the rainfall anomaly was about 29 % based on the annual average figures, although the rainfall distribution was not uniform. The crop production loss was recorded at 16.8 %. In the two consecutive years of 1999 and 2000, agricultural GDP in the EAC declined by 11 and 14 %, leading to a GDP growth rate of −5 and −5.8 %. An increase in temperature significantly lowers the value of output for Kenya, Uganda, and Rwanda.

Based on the study of economics of climate change in Kenya, it is reported that adaptation can reduce the economic costs of climate change but it too has a cost (SEI 2009). The costs of adaptation are still emerging. A number of categories of adaptation have been identified that relate to the balance between development and climate change. An initial estimate of immediate needs for addressing current climate impacts as well as preparing for future climate change in Kenya is US$500 million per year. The cost of adaptation by 2030 will increase: an upper estimate of the cost is likely to be in the range of $1–2 billion per year. The study has also prioritised early adaptation across the sectors. These studies demonstrate that adaptation has potentially very large benefits in reducing present and future damages. However, although adaptation reduces damages, it does not remove them entirely.

Research on adaptation to climate change in the agricultural sector indicates that the choices for adaptation depend on the available options in specific agroecological zones. Furthermore, the government can play a significant role by promoting adaptation methods appropriate for particular circumstances, crops, and agroecological zones. According to the United Nations Food and Agriculture Organization FAO (2011a), conservation agriculture (CA) provides many benefits, including to the environment, such as addressing land degradation. CA helps foster agrobiodiversity and other essential environmental services, which improve agroecosystem resilience, helping farmers to better face risks and uncertainties. The productivity and diversity of crops also increase incomes and improve rural livelihoods. CA practices such as using leguminous crops, crop residues, cover crops, and agroforestry enhance soil fertility and lead to the stabilisation of soil organic matter and in many cases to a heightened sequestration of carbon in the soils.

CA assists farmers in adapting to climate change by establishing conditions that increase agroecosystem resilience to stress. Increasing an agroecosystem adaptive capacity allows it to withstand climate variability better, including erratic rainfall and temperature variations and other unexpected events. Drawing on strong local community and farmers' knowledge and agrobiodiversity, ecological agriculture improves soil quality by enhancing soil structure and its organic matter contents, which in turn promotes efficient water use and retains soil moisture. Such conditions simultaneously enhance soil conservation and soil fertility, leading to increased crop yields (FAO 2011a). CA is claimed to be a panacea for the problems of poor agricultural productivity and soil degradation in sub-Saharan Africa, reported to increase yield, reduce labour requirements, improve soil fertility, and reduce soil erosion. It is thus being actively promoted by international research and development organisations. Some studies, however, raise concerns regarding the practicality of CA, which contributes to its low uptake in most sub-Saharan African countries (Giller et al. 2009). The concerns include decreased yield, increased labour requirement, and an important shift of the labour burden to women. This calls for critical assessment regarding under which ecological and socioeconomic conditions CA is best suited for smallholder farmers in the region.

According to Chakeredza et al. (2009), a number of organisations worldwide, for example, the FAO, are promoting the use of indigenous and locally adapted plants and animals as well as the selection and multiplication of crop varieties adapted or resistant to adverse conditions. The selection of crops and cultivars with tolerance to abiotic stresses (e.g., high temperatures, drought, floods, and high salt content in soil) allow harnessing genetic variability in new crop varieties. National programmes should have capacity built and long-term support to use these options. The study concludes that agroforestry can enhance adaptation to climate change through provision of diversified tree products and services.

The predicted effects of climate change must be introduced into development planning, including land-use planning, natural resources management, infrastructure design, and measures to reduce vulnerability in disaster reduction strategies. The array of adaptation options is very large, ranging from purely technological measures to managerial adaptation and policy reform. For developing countries, availability of resources and adaptive capacity building are particularly important. Based on anticipated climate change and impacts on water resources in Africa, the Intergovernmental Panel on Climate Change (IPCC 2001) identified four necessary adaptive strategies.

(a) *Adaptive measures*. Measures should be adopted that would enhance flexibility, resulting in net benefits in water resources (irrigation and water reuse, aquifer and groundwater management, desalinisation), agriculture (crop changes, technology, irrigation, husbandry), and forestry (regeneration of local species, energy-efficient cookstoves, sustainable community management).
(b) *Risk sharing*. A risk-sharing approach between countries will strengthen adaptation strategies, including disaster management, risk communication, emergency evacuation, and cooperative water resources management.
(c) *Enhancement of adaptive capacity*. Local empowerment is essential in decision making in order to incorporate climate adaptation within broader sustainable development strategies. Most countries in Africa are particularly vulnerable to climate change because of limited adaptive capacity as a result of widespread poverty, recurrent droughts, inequitable land distribution, and dependence on rainfed agriculture.
(d) *Diversification*. To minimise sensitivity to climate change, African economies should be more diversified, and agricultural technology should optimise water usage through efficient irrigation and crop development.

All of the above adaptive strategies need to have strong gender perspectives. These strategies must consider the physical, gender, and socioeconomic factors that create vulnerability. The reality of climate stresses combined with diverse socioeconomic and gender roles and uneven ownership of resources such as land make it necessary to re-examine the adoptive conditions based on realities on the ground. The diverse roles and responsibilities become very significant in adoption of climate change strategies for different categories of people. Gender inequalities in access to resources, such as land and other productive assets, including credit, extension services, information, and technology, must be taken into account with the root causes of gender inequality in developing mitigation activities and adaptation efforts.

As explained above, despite the usefulness of climate-smart initiatives in the East African countries, only very few initiatives are being realised. In Kenya, for instance, there are several ongoing initiatives through the World Agroforestry Centre (ICRAF), and a number of initiatives are being developed. By yielding a broad range of products, including fruits, fuel wood, timber, and resins, agroforestry helps farmers to diversify their incomes, providing them with greater protection against market failures and climate fluctuations. The use of nitrogen-fixing trees and shrubs increases soil fertility and crop yields. Trees also help farmers adapt to climate change, as perennial crops are better able to cope with droughts and floods than annual crops. Trees sequester much greater quantities of carbon than annual crops, and in some instances provide farmers with access to the carbon market. Agricultural carbon finance presents an opportunity for climate justice for smallholder farmers who are most vulnerable to climate change, while addressing the mitigation challenge. The triple win of higher yields, climate-resilient farming, and carbon sequestration is theoretically possible. However, these wins are subject to complex socioeconomic, political, and cultural conditions that have strong bearing on their achievements, as the KACP case of Kenya highlights. In any case, farmers have a right to informed engagement in such mitigation and adaptation programmes. Exclusion, marginalisation, and dependency may result from uninformed engagement and create new vulnerabilities. Capacity building about agricultural carbon finance for national policy makers and farmers is critical.

Regarding the whole aspect of carbon trading in Africa, the argument that carbon trading offers real benefits to the poor in Africa is simply not credible (Reddy 2011). It is found that if anything, offset schemes allow industrialised countries to maintain their affluent lifestyles by exporting the burden of reducing greenhouse gas emissions to countries in the South. It further argues that fundamentally, inequality is behind the climate problem, and the search for solutions must involve industrialised societies making fundamental structural changes to their lifestyles, energy practices, and their production and consumption systems.

2.3 Agricultural Policies for Climate Change Adaptation

Although the East African countries have developed policies and established institutions or structures for environmental management and climate change issues, there are still a number of gaps pertaining to mainstream climate change matters in sectoral plans and programs. Some key gaps were identified in the reviewed policies, macro strategies, and sectoral strategies and plans.

Most African countries gained independence in the 1960s, a time when central planning was widely seen as a promising strategy for economic development (Anderson and Masters 2008). In this environment, elected governments across Africa typically kept the marketing boards and other instruments for intervention that had been developed by previous administrations, expanding their mandate and increasing public employment, in many cases as a means for electoral politics. In the 1970s, growing fiscal deficits, current account imbalances, and overvalued exchange rates were supported by project aid and loans at a time of zero or negative real interest rates, as governments chose to ration credit and foreign exchange rather than expand the money supply. The result of growing government intervention was political instability and weak market institutions. It can be seen that during the first two to three decades, climate change issues were not key issues in the development agenda.

Most of the policies and strategies in the East African region, especially those produced prior to 2000 and before the production of NAPA, do not directly link to climate change matters. Even though they articulate matters that may contribute to climate change adaptation and mitigation, they have to be reviewed or implemented in the context of the changing climate, which has significant implications for sustainable natural resources management, sustainable development, and community livelihoods. This is largely attributed to the fact that climate change is an evolving and cross-sectoral concern, which requires proactive, collective, and gender response adaptation measures among interrelated sectors.

All the NAPA documents in the EAC have recognised the negative impacts of climate change on the main ecosystems in various ways depending on the disaster. Accordingly, drought is the single most important and widespread disaster in Uganda, Tanzania, Burundi, and Rwanda. According to the Government of Uganda (2007), the drought is increasing in frequency and severity, particularly in the semi-arid Cattle Corridor. It affects a wide range of ecosystems, sectors, and key social and economic programmes. Furthermore, storms, heavy rains, and floods are the second most important cluster of disasters. This cluster of disasters has negative impacts on key sectors such as water resources, health, soils, wildlife, and infrastructure. Loss of lives and physical injuries are associated with this cluster of disasters. The effects of this cluster of disasters are most pronounced in the highland ecosystems.

Recently, Burundi worked out a Biological Biodiversity National Strategy and Plan of Action (SNPA-DB). Burundi also submitted its first National Communication to the UNFCCC. Regarding the Convention to Combat Desertification, Burundi further developed a National Plan of Action to Combat Desertification (PAN-LCD) (Government of Burundi 2007). In Rwanda, with a present weak adaptative capacity to the climate change due to a high level of poverty, drought, recurrent floods, strong dependence on rainfed agriculture, and a serious energy crisis hindering human development, building adaptative capacity necessitates the integration of adaptation measures to climate change in the global strategies of sustainable development (Government of Rwanda 2006). This principle is strongly applied in the choice of immediate and urgent adaptation measures identified in the framework of Rwanda's NAPA by the analysis of coherence and synergies with the sectoral policies and strategies of the country.

Apparently, climate change has not thus far been adequately mainstreamed or integrated in sector-specific plans and strategies. Where efforts have been initiated, as in the water and agriculture sectors, there are still remaining implementation gaps. As such there is a need to develop climate change policy and legislation in the East African countries which will promote establishment of an institutional framework for mainstreaming climate change matters in sectoral plans and programmes. Shayo (2006) notes that the completed Tanzanian NAPA was prepared in order to look at the country's climate change-related vulnerabilities in various sectors which are important for the economy. The completion of the NAPA in Tanzania will certainly enable the country to further integrate adaptation issues in the development process.

For most of the countries in the East African region, agriculture is the key to achieving broad-based, pro-poor economic growth and attaining the MDGs. Throughout history, increases in agricultural sector productivity have contributed greatly to economic growth and the reduction of poverty (OECD/FAO 2006). However, in the last decades, both governments and the donor community for various reasons have neglected the agricultural sector in Africa. From the 1980s onward, agriculture became increasingly ignored in many developing countries. This happened both in development cooperation policies – where the share of agriculture dropped from 18 % in 1980 to 4 % in 2007 – and in national budgets. The share of official development assistance (ODA) to agriculture dropped significantly, falling from a peak of 17 % in 1979, the height of the Green Revolution, to a low of 3.5 % of total investment in 2004. It also declined in absolute terms: from US$8 billion in 1984 to US$3.5 billion in 2005 (World Bank 2008). Public investment in agriculture, particularly in smallholder agriculture and food security, from international donors and national governments declined sharply during the 1980s and 1990s, however, this period also witnessed strong growth in private sector agribusiness and the food industry, with structural shifts in research to private crop breeding and agrichemical development (de Janvry and Sadoulet 2010).

In assessing how much policy reform had taken place in Africa by the mid-1990s, how successful it had been, and how much more remained to be done, the World Bank (1994) concluded that progress had been made but reforms remained incomplete. The report also stressed that poor macroeconomic and sectoral policies were the main factors behind the poor performance of sub-Saharan Africa's economy between the mid-1960s and the 1980s. Food markets were controlled by state enterprises, which also monopolized the import and distribution of fertilisers and other inputs that were often supplied to farmers at subsidised prices and on credit. The prices farmers received were generally low because of taxation or high costs incurred by state enterprises. The negative impact of such policies on agricultural prices was particularly significant in the case of export crops. During this period, African governments followed a development strategy that prioritised industrialisation, with a clear bias against agriculture (Kherallah et al. 2000). Since the implementation of structural adjustment programmes promoted by international financial institutions in the 1980s and 1990s, policymakers and academics have argued about the causes of and solutions to the African crisis, as well as the impact of the structural adjustments (Mkandawire 2005).

Encouragingly, the New Partnership for Africa's Development (NEPAD), the economic programme of the African Union (AU), has recognised the importance of agriculture and wants to boost Africa's growth through agriculture-led development. This has led to establishment of two major initiatives, namely the Comprehensive Africa Agriculture Development Programme (CAADP) and African Peer Review Mechanism (APRM), NEPAD activities concerned with agricultural policies and institutions in sub-Saharan Africa.

- CAADP is directed at agricultural sector policies including:
  (a) Improving national agricultural policy frameworks
  (b) Strengthening institutions and governance
  (c) Enhancing agricultural productivity
  (d) Fostering trade, investment, economic growth, and sustainable development
  (e) Promoting regional integration
- APRM aims at improving national governance and institutional settings in general. Given the prominence of agriculture in the economies of Africa, APRM may be expected to influence the agricultural sector as well.

It is important to highlight some common weaknesses of both APRM and CAADP, which strongly hamper their effectiveness in influencing national agricultural policy processes and the policies themselves. According to Zimmermann et al. (2009), the key weaknesses are:

- Both initiatives, when implemented at the national level, were not well linked to ongoing, national policy processes but instead are stand-alone initiatives. Not enough care has been devoted to the docking of the processes onto and the channeling of the results into national processes. The implementation of the initiatives at the country level is planned without taking into account the existing policy cycles and windows of opportunities such as five-year plans, revisions of Poverty Reduction Strategy Paper (PRSP), or agricultural sector planning cycles. This, however, is crucially important because there can and should be only one relevant policy document per sub-sector. The incentives to adopt the results of the national exercises are not as high in cases such as immediate additional donor support or government spending. Therefore, it is difficult to create new windows of opportunities. In most cases, this is not even desirable inasmuch as reforms should not be bought but owned by convincing insiders. The initiatives do not sufficiently take into consideration the lengthy processes of agricultural policy-making, including parliamentary procedures that most democratic countries are committed to, particularly at the level of specific law formulation.
- Both APRM and CAADP tend to invite participation in an ad hoc manner. They both, and particularly CAADP, overestimate the capacity, especially of disadvantaged groups, to get involved in national policy processes. They do little to improve long-term and quality of participation in terms of participation capacity, networking, stabilisation of participatory structures, mandates of participants, and so on. Rural populations are easily left out in a self-organised process and disadvantaged in terms of representation by civil society organisations due to the low media presence and population literacy, leading to an urban bias.
- Similarly, APRM and CAADP overestimate the flexibility and the mechanisms of donor support and probably also the lack of willingness to align. Despite the lip service paid to agricultural development, the agricultural sector is nominally funded in aid allocations, although the food price crisis may have changed that recently. However, for governance issues in general, lack of interest is certainly not the case. Governance is rated very high on donor agendas. The fact that even the political governance findings of APRM are not acknowledged and supported quickly and massively by donors indicates that the lack of embeddedness into national policies (see above) and the lack of flexibility of donors may be important handicaps for such initiatives. Realignments are very slow, following the revision of key policies, and most often require lengthy adjustment processes such as bilateral negotiations and agreements. Donor representatives at the national level often do not have the mandate to react quickly.
- National and regional policy arenas are not yet well linked. The connections of agriculture, food security, and trade policies are not yet fully taken into account in setting the agenda for CAADP at the regional and national level. Although

much focus in the African regions is put on regional integration in general, the specific implications and regulatory consequences for agriculture are not yet fully recognised. The link is almost absent in APRM and theoretically strongly developed but in practice limited in CAADP. However, regional aspects of agricultural policy making are predicted to increase in importance, if not due to CAADP and agricultural policy mandates for Regional Economic Communities (RECs), then due to regional trade policies, which heavily affect agricultural sectors of member countries. For the time being, however, regional links in African agricultural policies are not yet very strong.

The process to develop the East African Community Climate Change Policy (EACCCP) was initiated in response to a directive by the EAC heads of state made during the 11th Summit of the Heads of State held in Arusha, Tanzania in 2009, to develop a regional climate change policy and strategies to respond urgently to the adverse impact of climate change, including addressing the challenge of food insecurity as a result of the extreme climatic conditions associated with climate change.

The aim of the policy is to address the adverse impacts of climate change in the region, in response to the growing concern about the increasing threats of the negative impacts of climate change to national and regional development targets and goals. In addition, the development of the policy is in fulfillment of the objectives of the EAC: to develop policies and programmes aimed at widening and deepening cooperation among partner states in accordance with the Treaty for the Establishment of the EAC. The policy is consistent with the fundamental principles of the treaty establishing the EAC and principles of international environmental law, according to the EAC Protocol on Environment and Natural Resources, the Protocol on Sustainable Development of Lake Victoria Basin, and the UNFCCC. The preparation of the policy was also guided by emerging issues and challenges faced by the region and potential benefits and opportunities in light of the increasing climate change.

The policy was prepared in a consultative and participatory approach by experts drawn from the five EAC partner states (Burundi, Kenya, Rwanda, Tanzania, and Uganda) and facilitated by the EAC Secretariat and the Lake Victoria Basin Commission Secretariat. The effective implementation of the prioritised climate change adaptation and mitigation measures identified by the policy will depend on collaborative efforts by all relevant actors towards minimising the overall affects of climate change and consequently lead to regional social and sustainable economic development.

2.4 Gaps in Climate Change Adaptation Research and Policy in the Agricultural Sector

Agriculture is one of the most widely studied sectors with respect to the effects of climate change, as it is considered one of the most vulnerable sectors. Climate change and variability present new development challenges, particularly in sub-Saharan African countries where the majority of the population depends on climate-sensitive activities, in particular agricultural production (FAO 2010a; IFPRI 2010; Thompson et al. 2010).

It is further important to look through a gender lens and analyse the diverse situations of men and women across socioeconomic backgrounds when planning strategies. Each community has its own unique and dynamic situation. Gender roles and privileges vary from one location to another. Informed adaptation planning necessitates detailed gender analysis of each community. Sex-disaggregated data should be collected where possible to understand how men and women are being affected differently and how adaptation strategies may have different impacts on them. Analyses should include effective participatory processes that are gender responsive.

During the past 20 years in Africa, a great deal of emphasis has been placed on the development of national agricultural research strategies and priorities, which have often occurred within the context of World Bank loans (IAC 2004). In addressing research issues that address climate change adaptation the following four African farming systems have been reported to offer the greatest potential for reducing malnutrition and improving agricultural productivity:

- The maize-mixed system, based primarily on maize, cotton, cattle, goats, poultry, and off-farm work
- The cereal/root crop-mixed system, based primarily on maize, sorghum, millet, cassava, yams, legumes, and cattle
- The irrigated system, based primarily on rice, cotton, vegetables, rainfed crops, cattle, and poultry
- The tree crop-based system, based primarily on cocoa, coffee, oil palm, rubber, yams, maize, and off-farm work

The literature review indicates that there is a lack of detailed and systematic analysis of how climate change and variability affect the various agroecological zones of the East African Region. This implies that more research is needed to examine the existing farming systems to ascertain the effect of climate change in each of the respective agroecological zones. The literature review further shows that more research has been conducted in analysing the effects of climate change and variability on crop production. Apparently, little has been documented regarding the effect of climate change on the agricultural production systems in the East African region. The analysis of the gender implications of climatic changes on the agricultural sector also does not feature much in most of the articles reviewed. In considering how the impacts of climate change influence coping mechanisms, it is important to consider how both proactive and reactive adaptation mechanisms affect men and women differently. Without a gender-sensitive approach to adaptation planning, it is impossible to develop strategies that will meet the needs of both men and women and be effective in the long term.

CA appears to have potential in strengthening adaptation and resilience. However, empirical studies are needed in different agroecological zones to test its contribution to adaptation planning, including mainstreaming climate change issues in the agricultural sector. CA is claimed to be a panacea for the problems of poor agricultural productivity and soil degradation in sub-Sahara Africa. Yet, according to some studies there are concerns regarding the practicality of CA, which contributes to its low uptake in most sub-Saharan African countries. A great deal of the literature reviewed does not discuss much on the challenges associated with the employment of such practices. This calls for rigourous research on the applicability of CA in enhancing resilience in the various agroecological zones of the EAC in the context of climate change.

3 West Africa

There is evidence globally of changing climate, but there is uncertainty regarding the pace, extent, and effects on subregions, nations, communities, and sectors as well as adaptation to climate change. This uncertainty renders policy making difficult and underscores the need for Africa to build its knowledge base to strengthen the capacity of regional and national institutions in developing the evidence base for addressing climate change adaptation issues. The overall objective is to enhance the knowledge base and to support research-based policy formulation for climate change adaptation in the agricultural sector in West Africa. The expected outputs are:

1. A synthesis of research related to climate change in the agricultural sector accomplished
2. Research and policy gaps related to climate change adaptation in the agricultural sector identified
3. Key stakeholders and opportunities in climate change adaptation in the agricultural sector identified

3.1 Overview of Agriculture in West Africa

3.1.1 Climate Change Challenges

Key Characteristics of the Climate

Jalloh et al. (2011a, b, 2013) have summarised the key characteristics of climate in West Africa: average annual rainfall of 250–550 mm; length of growing period (LGP) of 60–90 days in the semi-arid zone (Sahel); 550–900 mm, LGP of 90–165 days in the Sudan savannah (dry subhumid); 900–1500 mm, LGP of 165–270 days in the Guinea savannah (subhumid); and 1500–4000 mm, LGP of 270–365 days in the coastal zone (humid). Rainfall is subject to a high degree of spatial and seasonal variability because of the modulation of the seasonal cycle linked to the position of and intensity of the intertropical convergence zone (ITCZ) plus the magnitude of rainfall due to squall lines. As a result, seasonal characteristics of monsoon rainfall (onset, length, and cessation of the rainy season), seasonal rainfall amount, and the intraseasonal distribution show high interannual variability. Sunshine is uniformly high, especially in the semi-arid and arid zones (2500–3000 h per annum). Temperatures are high across the region, with a mean annual temperature above 18 °C; within 10 °C north and south of the equator mean annual temperature is about 26 °C with a range of 1.7–2.8 °C, the diurnal range being 5.5–8.5 °C. Between latitude 10°N and the southern parts of the Sahara, the mean monthly temperature can rise up to 30 °C. Maximum temperatures range from 30 to 33 °C in countries along the coast to 36–39 °C in the Sahel.

Climate Change Projections for West Africa

Climate change scenarios are uncertain for West Africa, especially when it comes to rainfall. Namara et al. (2011) reported that global circulation models (GCMs) predict the start of the rainy season 1–2 months earlier than what is observed and that the observed Sahelian climate between 1961 and 1970 is at variance with the climates simulated by six GCMs of the Intergovernmental Panel on Climate Change (IPCC). The models show a marked rainy season almost throughout the year, along with a considerable bias (140–215 mm/year) in annual aggregate rainfall estimates as compared to the observed data. There are also discrepancies between models; in the coastal zone, for example, Sierra Leone, ECHAM4, and HADCM2 give rainfall values similar to observed values whereas CSIRO-TR and UKTR give lower values than observed (Jalloh et al. 2011b). The average rise in temperature between 1980–1999 and 2080–2099 is predicted to be +3 °C in the coastal zone of West Africa, rising to +4 °C in the western Saharan region (IPCC 2007a), that is, 1.5 times the global average (according to the most recent IPCC assessment, global mean surface change for 2016–2035 relative to 1986–2005 will likely be in the range of +0.3 to +0.7 °C. For the period 2000–2050, Nelson et al. (2010) reported lower temperature increases for West Africa (Table 2). Increase in intensity of rainfall per rainfall event is predicted across Niger, Mali, and Burkina Faso, whereas Senegal and Southern Nigeria may see decreases in rainfall per rainy day (Ericksen et al. 2011).

Table 2 Temperature and precipitation scenarios for West Africa from general circulation models (GCM)

GCM	Change in precipitation (%)	Change in precipitation (%)	Change in average minimum temperature (%)	Change in average maximum temperature (%)
CNRM-CM3	8.2	51.3	2.75	2.03
CSIRO MK30	1.9	11.7	2.05	1.73
ECHAM 5	1.3	7.9	2.21	1.98
MIROC 3.2	−1.7	−10.9	2.26	1.57

Adapted from Nelson et al. (2010)

Overview of the Range of Possible Impacts of Climate Change in the Agricultural Sector

There are several likely impacts of climate change on agriculture in the region. Land suitable for cropping and length of growing period could change, with the Sahelian zone potentially the hardest hit. The effects of the rise in temperature and extreme rainfall events on crop yields will generally be negative and crops least tolerant to drought will suffer most. Farming calendars will change. Climate change may entrain deforestation as more lands are brought under cultivation. Mangrove forest in coastal areas, some used for rice cultivation, may be damaged. Flows of major rivers would fall, in a situation of increasing demand for irrigation water and population growth. Rise in sea level will lead to entry of salty water into agricultural lands and cause degradation. By 2100, farm sector losses due to climate change and variability could reduce regional GDP by 2–4 % (Namara et al. 2011). These effects would be moderated by local conditions and factors such as availability and accessibility of adaptation options, markets, settlement patterns, institutions, and policies.

Overview of Key Causes of Vulnerability in the Agricultural Sector

Three major components or causes (social, economic, and environmental) of vulnerability of agriculture in relation to climate change have been identified (Brooks et al. 2005; Adebo and Ayelari 2011). Factors contributing to social vulnerability include rapid population growth, poverty, hunger, poor health, low levels of education, gender inequity, fragile and hazardous locations, frequent natural disasters, conflicts, poor national and local governance (including the marginalisation of certain groups in decision making), and lack of access to resources and services including knowledge and technology. Economic vulnerability refers to the importance of agriculture in the national economy, trade and foreign exchange, aid and investments, international prices of agricultural commodities and inputs, and production and consumption patterns. Regarding environmental vulnerability the concerns are for management of natural resources, such as land degradation, water scarcity, deforestation, and the threat to biodiversity.

3.1.2 Implications of Climate Change for Other Key Challenges (and Opportunities) for the Agricultural Sector

Water Resource Supply, Demand, and Governance Challenges

Detailed, up-to-date information on surface and underground water resources in sub-Saharan Africa (SSA) is scarce, but it is known that between 1971 and 1989 there was about a 30 % reduction in the flow of the River Niger and a 60 % reduction in that of the River Senegal and River Gambia (IUCN 2004; Namara et al. 2011). Water resources are much greater in the coastal compared to the Sahelian

Table 3 Major international water basins and irrigation potentials in West Africa

Basin	Countries	Area (km^2)	Irrigation potential (ha)
Lake Chad	Cameroon, Chad, Niger, Nigeria	2,381,635	1,163,200
Niger	Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Guinea, Mali, Niger, Nigeria	2,273,946	2,816,510
Senegal	Mali, Senegal, Guinea, Mauritania	483,181	420,000
Volta	Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, Togo	394,196	1,487,000

Adapted from FAO (2005)

zone, but the former can still have problems of scarcity. Molden et al. (2007) distinguished between physical scarcity of water and economic scarcity and classified countries in the coastal zone as experiencing economic scarcity, that is, investments needed to keep up with growing water demand are constrained by financial, human, or institutional capacity, although water is physically available.

Rainfed production (highly susceptible to climate change) accounts for about 75 % or more of agricultural production across West Africa (Molden et al. 2007). However, only 15–30 % of the rainfall is used as productive 'green water', that is, water stored in the soil; in arid areas it may even be below 10 % (Shah et al. 2007). The substantial irrigation potentials of four major international water basins in West Africa, each providing water to four or more countries, are shown in Table 3.

Conflicting needs (dams for irrigation and energy) have contributed to the decline of the water resources of Lake Chad, illustrating that governance of the international river basins cannot be done unilaterally and requires cooperation of the countries sharing the waters.

West African countries have varied challenges and opportunities in managing the impacts of climate change on water resources. In general, there are negative implications for the following: water quality (salinity in coastal areas), surface and groundwater systems (drop in level of lakes such as Lake Chad), precipitation, sea level rise, and the dynamics of oceans (Urama and Ozor 2010). A good example is Nigeria, which has an 800 km low-lying coastal belt running from Lagos to Calabar. Lagos, Africa's most populous city, is seriously affected by sea level rise. Flooding has resulted in the removal of beach fronts and sometimes adjacent roads, leading to acute traffic disruption and destruction of property, social conflicts, and migration. In the semi-arid areas such as Niger, pastoralists migrate in search of water and seasonal grazing, leading sometimes to conflicts with settled agrarian communities.

Land Resources

Climate change can result in increased temperatures, reduced rainfall, or excessive rainfall events leading to a reduction in soil vegetative cover and serious water and wind erosion, and therefore soil crusting and land degradation. Lands in coastal areas are being degraded from the intrusion of salt water resulting from a rise in sea levels. A reduction in agricultural production is the overall consequence.

Studies of the Niger Basin showed that threats to livelihoods and ecosystems through deterioration in the natural resource base have been posed by a combination of population growth, unsustainable resource use, and deteriorating climatic conditions (Namara et al. 2011). However, it is difficult to separate the effects of climate change from other stresses on land resources. Le et al. (2012) used response of green biomass to rainfall to separate areas of 'human induced decline biomass' from 'climate driven dynamics' in the Volta Basin. Their study, based on datasets covering 1982–2003, showed that land degradation occurred in 8 % of the Volta Basin (83 % of which is Ghana and Burkina Faso), but that when atmospheric fertilisation (caused by CO_2 and NO_x in the atmosphere) is considered, up to 65 % of the land is degrading in terms of soil quality and vegetation productivity. The degradation was most severe in woodland (12,200 km^2), agricultural land (8300 km^2), shrub land (7300 km^2), and dense woodland (1600 km^2).

Soil nutrient depletion (soil mining) contributes to poor soil quality. Crasswell et al. (2004) reported moderate to high nutrient ($N+P_2O_5+K_2O$) losses in several countries in West Africa for the period 1996–1999 as follows: Mauritania, 58 kg/ha; Burkina Faso, 54 kg/ha; Ghana, 53 kg/ha; Nigeria, 50 kg/ha; Mali, 45 kg/ha; and Senegal, Benin, and Niger, about 38 kg/ha each. Country-level soil mining data, however, may hide hotspots requiring urgent attention (Dreschel and Gyiele 1999).

Using land for growing nonfood crops such as biofuels, sometimes in the context of land grabbing by multinational companies from small-scale farmers, presents opportunities for diversification in response to climate change and increased incomes of rural communities and increased national GDPs (Ngigi 2009), but caution is required because these crops may compete with food crops for land, nutrients, and water, resulting in landless people and social unrest. Biofuel plants such as Jatropha are becoming popular in Mali and Ghana.

Use of Local and Indigenous Knowledge and Its Combination with Scientific Knowledge

The term indigenous knowledge refers to knowledge systems developed by a community in a particular place over time, as opposed to scientific knowledge. West African crop farmers have coped with changing environments, sometimes due to climate variability. Despite some successes of indigenous coping strategies, there is evidence of breakdown because of a rapidly changing environment in terms of land use, sociopolitical, and cultural stresses (IPCC 2007a). Dieye and Roy (2012) reported from a case study in the semi-arid north of Senegal that although crop farmers have a clear appreciation of changes in natural resources, few new adaptive/coping strategies to climate change beyond traditional ones were envisaged. Traditional responses may not be adequate at present and especially in the future climate change stresses, and may even lead to unsustainable responses in the longer term (DFID 2004). Rather than utilising indigenous knowledge on its own, or discarding it completely, its incorporation into climate change policies can lead to the development of effective adaptation strategies that are cost effective and sustainable. Indigenous knowledge provides suitable entry points for research and development of climate change adaptation practices (FAO 2008).

Climate Change and Conflicts

The underlying causes of conflicts are complex and may be political and social, but climate change may contribute to conflicts between states and within states because of competition for water use if the increased supply to meet growing demand cannot be assured (Niasse 2005; Urama and Ozor 2010). When water supply is short, pastoralists come into conflict with crop farmers. Such conflicts can be so serious that they result in deaths on both sides, as happened in Nigeria between the Fulani cattle herders and sedentary crop farmers over grazing land and water bodies. These kinds of conflicts amongst smallholders are frequent in other parts of the semi-arid zone of West Africa. The drying up of Lake Chad, to which climate change has contributed strongly, has led to confrontations between fishermen, farmers, cattle herders, indigenous Chadians, and Chadians from elsewhere (Urama and Ozor 2010). Land degradation through salinisation and consequent shortage of land might also encourage conflicts. However, Sayne (2011) observed that attributing conflicts to climate change in Nigeria calls for caution because the scientific, social, economic, and political implications of a changing climate in the country are poorly understood. Unresolved conflicts would certainly increase vulnerability to climate change.

3.2 Vulnerability and Adaptation of Agricultural Systems

3.2.1 Vulnerability and Adaptation of Crop Farming Systems

Scientific Evidence for Implications of Climate Change for Crop Farming in a Multistressor Context

Vulnerability to climate change is a state that is governed not only by climate change itself, but by multiple processes and stressors (CGIAR 2009). Poverty, access to land, soil nutrient mining, use of low-yielding crop varieties susceptible to pests and diseases, high postharvest losses, and poor access to credit and markets are all challenges facing the smallholder. The relative contribution of climate change to low agricultural productivity, taking all the other challenges into consideration, is difficult to assess quantitatively. Several GCMs including CSIRO-MK 3.0, MIROC 3.2, CNRM-CM 3, and ECHAM 5 have been used to outline scenarios of climate change by region, broad agroecology, and country. Although increasing temperatures in the Sahel are clearly indicated by the GCMs, there is some uncertainty in rainfall-related projections for West Africa. This uncertainty carries over when crop simulation models are integrated into GCM scenarios (Mertz et al. 2009).

The results of modeling studies have been reported for millet, sorghum, maize, rice, groundnut, beans, cassava, cocoyam, and cotton in West Africa (Huq and Reid 2005; Sarr et al. 2007; Nelson et al. 2010; Jalloh et al. 2013). Roudier et al. (2011), performed an analysis of 16 modeling studies and concluded that a wide spread of yield changes ranging from −50 to +90 %, with a median of −11 % for West Africa. The predicted impact is larger in the northern Sudano–Sahelian countries (−18 %) than in the southern Guinea countries (−13 %) and the negative impacts on the crop productivity increase in severity as warming intensifies. The negative impact on yield was attributed mainly to projected temperature increases, although rainfall (uncertain to predict) has the potential to reduce or increase this impact. Apart from temperature and rainfall, increases in the concentration of carbon dioxide in the atmosphere as a result of climate change may have direct impacts upon yield levels of certain crops.

Recently Jalloh et al. (2013) employed the same models and parameters for all 11 West African countries and predicted that there will be a significant continuous decline in crop yields between 2000 and 2050 if no adaptation measures are undertaken. CSIRO and MIROC models predict a general decrease in maize yields of 5–25 % over baseline in most parts of the countries which lie on the southern coast of West Africa and a yield increase of 5–25 % in the Sahel zone. Both models indicate a yield decline in the northernmost parts of Mali, Burkina Faso, and Nigeria. Table 4 shows predicted production changes by country, assuming increased use of inputs (including improved varieties) and improved management practices. The models predict 5–25 % drop in yields of sorghum across most parts of West Africa, with yield losses greater than 25 % in some parts of Togo, Benin, and adjacent areas of Ghana and Nigeria. Yields of rainfed rice are predicted to decline by 5–25 % in most parts of Cote d'Ivoire, Ghana, and Togo based on CSIRO and MIROC and in Nigeria based on CSIRO. For groundnut, the two models predict decreases in yields of 5–25 % across most parts of West Africa, but lower yield changes in Sierra Leone, Liberia, and Guinea. Yield increases of 5–25 % are predicted for some parts of northern Cote d'Ivoire, Ghana, Burkina Faso, and Nigeria.

Apart from crop yields, effects of climate change have been assessed in terms of crop revenues and length of growing period. Kurukulasuriya and Mendelsohn (2008) estimated a multinomial logit to predict the probability of agroecological zones. A model was then used to calculate baseline values of cropland and revenues and estimates of the impacts of climate change made on them. They reported reduction in crop revenue in West Africa of between US$9.2 billion (−17 %) and US$17.4 billion (−32 %) for the Parallel Climate model (PCM) and the Canadian Climate Centre model (CCC), respectively, by 2100. Jones and Thornton (2009) studied arid and semi-arid zones of sub-Saharan Africa, including West Africa and found that under scenarios in which the emission of carbon is high the number of reliable growing days (RGD) would drop below 90 days for several hectares of marginalised land. For a low-emission scenario the acreage would reduce by 50 %. The significance of the finding is that if RGD drops below 90, rainfall may be so inadequate

Table 4 Changes in area, yield, and production for maize in West Africa under A1B scenario

Country	2010			2050					
	Yield (tons/ha)	Area (thousands of ha)	Production (tons)	Yield (tons/ha)		Area (thousands of ha)		Production (tons)	
				Min	Max	Min	Max	Min	Max
Benin	1.08	748	810	1.87	2.08	886	929	1660	1911
Burkina Faso	1.41	458	646	2.20	2.61	408	424	900	1105
Cote d'Ivoire	1.11	745	824	1.98	2.09	787	825	1601	1661
Gambia	1.93	16	31	2.55	2.73	17	18	43	48
Ghana	1.52	825	1255	2.44	2.59	945	990	2311	2538
Guinea	1.15	138	159	2.14	2.29	161	168	344	386
Guinea Bissau	1.90	16	31	2.03	2.15	18	19	37	41
Mali	1.39	381	531	2.31	2.61	304	313	703	803
Niger	0.78	4	3	1.57	1.69	1	2	2	3
Nigeria	1.29	4696	6070	1.74	1.90	4405	4829	7664	9181
Senegal	1.98	132	263	2.76	2.90	144	151	398	439
Sierra Leone	1.92	10	20	2.98	3.10	10	11	30	33
Togo	1.11	477	531	1.78	2.01	318	334	567	661

Adapted from Nelson et al. (2010) and Jalloh et al. (2013)
Note: A1B scenario assumes fast economic growth, a population that peaks in mid-century, and the development of new and efficient technologies, along with the balanced use of energy resources

that maize cultivation, with the common varieties, will not be possible and even the cultivation of millet will be difficult.

Options for Strengthening Adaptive Capacity and Supporting Crop Farming

1. *Research approach and options*: The International Development Research Centre (IDRC) and the UK Department for International Development (DFID) through their shared programme, Climate Change Adaptation in Africa (CCAA), have reported success stories with the use in West Africa of Participatory Action Research as a tool for strengthening smallholders' indigenous adaptive capacity to climate change. The approach favours joint identification of climate change related problems and probable solutions, practical action, and shared learning among researchers and many of those most affected: farmers, village elders, meteorologists, agronomists, academics, local leaders, government officials, and civil society organisations (Gologo 2012). Another example of a participatory approach being used in adaptation to climate change in West Africa is the testing, with the UN Food and Agriculture Organisation

(FAO) support, of climate change best practices and technologies in Farmers Field Schools in Burkina Faso (GEF 2012) and in Liberia (Government of Liberia 2013). Nevertheless, the largest part of the knowledge obtained on best bet technological options has been through conventional research methods.

A number of research and development practitioners have advocated the use of one or more of the available adaptation options which are in accord with the aspirations of the National Adaptation Programmes of Action (NAPAs) and national documents, to improve the response of farmers to climate change and variability and support crop farming (Howden et al. 2007; Harrington et al. 2008; Ngigi 2009; Below et al. 2010; Adesina and Odekunle 2011; World Bank 2011; Farauta et al. 2012). Strengthening the capacity of farmers involves making adaptation options available to them and accessible by them as well as providing training and extension services and access to credit and markets (Zorom et al. 2013). They include use of stress-tolerant varieties; adjustment of cropping calendars and cropping systems, crop residue management, integrated soil fertility management, conservation agriculture, soil and water management, agroforestry, biotechnology, reduction of postharvest losses, value addition, weather forecasting and early warning systems, insurance for producers, and diversification and migration. Examples of research findings related to climate change adaptation in West Africa on some of these options are presented in the following subsections.

2. *Improved varieties tolerant to climate change stresses*: Plant breeders at Africa Rice, the Africa Rice Centre, have identified several traits that contribute to drought-tolerant and rice breeding materials, including some found in the indigenous African rice *Oryzae glaberrima*. Molecular markers are being identified which tag genes that contribute to drought tolerance, so as to speed up development of drought-tolerant lines. Gene pools of wild or weedy rice species *O. barthii* and *O. longistamata* are also being exploited (Manneh et al. 2007). African rice has combined the useful traits of *O. sativa* and *O. glaberrima* and developed interspecific lines (NERICAs). Many are weed competitive, tolerant to major pests and diseases, early maturing, and high yielding. Rice varieties with some tolerance to salinity are available (Rhodes 1995). The International Maize and Wheat Improvement Center and the International Institute of Tropical Agriculture (IITA) have developed and released in West Africa several new maize hybrids and open pollinated varieties which are drought tolerant and produce 20–50 % higher yields than other maize varieties under drought conditions (CGIAR 2010). To improve adoption rates by local communities, research institutions throughout West Africa where IITA and Africa Rice operate now engage in the participatory varietal selection, wherein farmers are actively involved in the development of improved crop varieties.
3. *Adjustment of planting date and cropping systems*: Kra and Ofosu-Anim (2010) did mathematical modelling of daily maximum and minimum temperatures for selecting the best planting date so as to minimise the total irrigation water requirements for maize in a situation of water shortage and competing uses. They showed that up to 96 % more irrigated areas could be brought under irri-

gation without additional irrigation water through optimum planting date selection in the coastal savannah zone of Ghana. In another modelling study involving Ghana, Burkina Faso, Niger, and Senegal, date of planting in combination with crop sequence was found to be an adaptation strategy worthy of further study. However, the implications of shift in date of planting and change of cropping systems for labour use have to be considered (Waha et al. 2013).

4. *Crop residue management*: Smallholder farmers in West Africa usually dispose of crop residues by burning, thereby releasing CO_2 into the atmosphere. Numerous reviews have pointed out the benefit of crop residue restitution of soil organic matter content, water holding capacity, and agricultural productivity in West Africa (Bationo et al. 1996; Bationo and Buerkert 2001; Schlecht et al. 2006). The practice is therefore considered climate smart. Rhodes (1995) used a nitrogen (N) balance model and predicted a relative loss in labile soil organic nitrogen over 10 years of 158 kg/N/ha for a system of fertiliser N plus maize crop residue restitution compared to 225 kg N/ha for fertiliser N alone in the semi-deciduous forest zone of Ghana. Gonzales-Estrada et al. (2008) showed that a crop simulation model and a household-level multiple criteria optimisation model could be used to identify a set of best practices that can sequester carbon (increase soil organic matter) and increase farm income in the Upper West Region (Guinea/Sudan savannah transition zone) of Ghana. There is spatial variability in soil organic matter content around homesteads and farms, especially in the Sahel, and field dispersion is an effective strategy to manage agroclimatic risk of crop failure (Rhodes et al. 1996; Akponikpe et al. 2011). In a study conducted in the Upper East Region (Guinea/Sudan savannah transition zone) of Ghana (MacCarthy et al. 2009), the Agricultural Production Systems Simulator model (APSIM) predicted that the amount of fertiliser N needed for sorghum in homestead fields (where crop residues are returned to the soil) would be half of that required in bush farms. Rate of residue application seems to affect the performance of APSIM; Akponikpe et al. (2010) concluded that the model performs satisfactorily for simulating millet response to fertiliser and manure in Niger when P is not limited, but only for low rates of crop residue application (≤900 kg/ha crop residue).
5. *Integrated soil fertility management*: In its basic form, integrated soil fertility management (ISFM) stipulates the judicious combination of organic materials (animal manures, crop residues, green manures, or composts) with mineral fertilisers and use of N-fixing legumes to improve fertiliser use efficiency and soil and crop productivity (Vanlauwe 2004). For swamp rice cultivation, improving fertiliser efficiency by reducing losses of N_2O gas to the atmosphere is climate smart. However, the Participatory Action Research (PAR) was successfully used in Ghana's forest/savannah transition zone as an entry point, empowering communities to self-mobilise and self-organise into colearning and experimenting with ISFM technologies as an adaptation option to climate change (Mapfumo et al. 2013). Using participatory action research, ISFM was found to work in Ghana, Mali, and Burkina Faso, but it was concluded that best-fit options based on detailed analysis of the specific farming context, including

goals, resources, and biophysical environment were required instead of relying on blanket recommendations (CCAA 2012). Kato et al. (2011) also cautioned that adequate attention should be paid to biophysical conditions of the plots and the household access to labour endowments, farming equipment, and land tenure for ISFM to be scaled up and widely used in West Africa.

6. *Conservation agriculture and carbon sequestration*: The key principles of conservation agriculture are:

    (a) Minimising mechanical soil disturbance (involving use of herbicides to control weeds)
    (b) Maintaining permanent soil cover with organic mulch
    (c) Diversification of crop rotations

    CA resulted in increase in soil organic matter and carbon sequestration in Mali (Doraiswamy et al. 2007). Bayala et al. (2012) did a synthesis of reports on the effects of components of CA on yields of maize, millet, and sorghum in Burkina Faso, Mali, Niger, and Senegal. The practices compared were:

    (a) Parkland trees associated with crops
    (b) Coppicing trees
    (c) Green manure
    (d) Mulching
    (e) Crop rotation
    (f) Traditional soil/water conservation

    They found significant variability in cereal response with all practices, but the average effects of CA on crop yields were more positive than negative. Response to green manure and mulching were the best. The findings underscore the need of avoiding a 'one size fits all' mentality. Despite being widely promoted as climate smart, its uncritical use by smallholders should be avoided because of the implications of additional labour for weeding for women and the need for further fine tuning to the conditions of smallholders (Giller et al. 2009, 2011a).

7. *Soil and water management*: It is well known that good soil and water management are prerequisites for efficient use of water, especially in situations of declining rainfall in the Sahel and semi-arid zones (Ngigi 2009). Thus, these are invaluable in combating the effects of climate change. Technologies of soil and water management including provision of soil cover, minimum or no tillage, rainwater harvesting, and irrigation are available. However, very little information is available on the economics of soil and water management on farmers' fields. Reij and Smaling (2008) estimated the costs of establishment and maintenance of zaï pits for soil, water, and fertility management at US$250/ha/year and US$65/ha/year, respectively. Fox et al. (2005) found that the combination of rainwater harvesting and surface irrigation yielded a net profit of US$151 to US$622/ha for smallholder irrigation in Burkina Faso.

8. *Agroforestry*: The use of trees and shrubs in agroforestry systems helps to tackle the triple challenge of achieving food security, mitigating climate change,

and increasing the adaptability of agricultural systems (FAO 2010b; Torquebiau 2013). Recovery from extreme weather events or market failures is an attribute of agroforestry systems because of the diversified temporal and spatial management options. For these reasons agroforestry is said to be climate smart. Research on agroforestry in West Africa as related to climate change has focused on its carbon sequestration potential and effect on soil fertility (Asare et al. 2008; Takimoto et al. 2008). Thus, carbon sequestration by traditional agricultural parklands in Senegal was estimated at only 0.4 tons/ha/year with a potential of 20 tons/ha in 50 years. This finding led to the conclusion that in the West African Sahel, agroforestry seems more valuable for adaptation than for mitigation (Torquebiau 2013). In Mali, Takimoto et al. (2008) reported that the potential to sequester carbon in traditional agricultural parkland was greater than in live fences and fodder banks. Concerning the coastal zone countries, it was shown in Ghana that traditional shaded cocoa stored 155 tons/ha compared to 72 tons/ha for unshaded intensive cocoa (Asare et al. 2008). The productivity of the cocoa was higher in unshaded farms than shaded farms, indicating a tradeoff between cocoa productivity and carbon stocks. The fertility of the soil under shaded cocoa was greater than under unshaded cocoa.

9. *Biotechnology*: Genetically modified organisms (GMOs) constitute a technological option for adaptation to climate change for developing countries, for example, through improved effectiveness of insect pest management (Howden et al. 2007). The Economic Community of West African States (ECOWAS), West African Economic and Monetary Union (WAEMU), and Comité permanent inter-État de lute contre la sécheresse au Sahel (CILSS) are harmonising their regional biosafety regulations (Knight and Sylla 2011) and Burkina Faso, Mali, Ghana, and Nigeria have legislation allowing field trials of GM products. Burkina Faso is at the front in West Africa in the application of biotechnology for improving crop productivity. A survey conducted in 2009 in Burkina Faso showed that insect-protected biotech cotton increased yields by 18 % over conventional cotton and resulted in increased income of US$62/ha over conventional cotton (Vitale et al. 2010). By 2010/2011 yields had increased by 66 % (Knight and Sylla 2011). In addition, biotech cotton made farmers less dependent on fertilisers and better able to adapt to rainfall shortage in Burkina Faso. Biotech cowpea has recently been approved for confined field trials in Burkina Faso and Nigeria (Knight and Sylla 2011).
10. *Reducing postharvest losses, improving marketing, and value addition*: Agricultural productivity can be improved not only by increasing yields, but by reducing postharvest losses, which are considerable in West Africa. In Sierra Leone in the hot humid coastal zone, research (Government of Sierra Leone 2004) has shown a range of losses depending upon the produce: 20 % for rice and 40–50 % for fruits and vegetables. The recovery rate is 40–50 % of oil from palm bunches and 40 % for green coffee beans by traditional methods. Technology is available to reduce these losses substantially, for example, rapid drying after harvest to moisture content of 14 % or less, and use of mechanical rice and coffee hullers and oil palm mills. Value addition, through processing of

available improved methods (e.g., mechanical cassava graters for gari production) and improved infrastructure to access markets also reduces losses. The predicted temperature rise from climate change will increase postharvest losses of annual crops, and thereby vulnerability of farmers to climate change, if corrective measures are not undertaken.

11. *Assessment of 'best practice' technologies*: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) researchers (Cooper et al. 2009) tested the hypothesis that in the medium term (2010–2050), ICRISAT is well placed to assist farmers in mitigating the challenges and exploiting the opportunities posed by climate change, through application of existing knowledge on crop, soil, and water and the redeployment and retargeting of the existing germplasm of its mandate crops. The ex-ante analysis involving the GCMs, APSIM, and the Decision Support System for Agrotechnology Transfer (DSSAT) showed that adoption by farmers of existing recommendations, even under climate change will result in substantially higher yields than farmers are currently obtaining. Other CGIAR centres covering West Africa – IITA, Africa Rice, International Maize and Wheat Improvement Center and the International Water Management Institute (IWMI) – have also developed improved technologies for their mandate commodities and published Best Practices (CGIAR 2008). CORAF/WECARD in collaboration with CTA has also published Best Practices developed by the National Agricultural Research Systems (CORAF/WECARD 2011). According to Lybbert and Sumner (2010), best practices should be regarded as providing a source of tactical responses (short term) to a changing climate as opposed to an acceptance of untested strategic responses (long term).
12. *Weather forecasting and early warning systems*: Modelling studies have been done to get a better understanding of the utility of weather forecasts to smallholders. Sultan et al. (2010) reported on the ex-ante economic value of seasonal forecasts in the Nioro Rip semi-arid zone of Senegal, using a bioeconomic model to simulate the decisions of farmers with access to a priori information on the quality of the next rainy season. They showed that predicting a wetter than average rainy season would expose farmers to a high risk of failure by favouring cash crops such as maize and groundnut that are very vulnerable to drought. On the other hand, for a drier than average rainy season forecast, farmers respond to minimise the climate risk by choosing crops such as millet and sorghum, which can tolerate higher rainfall in the case of the forecast being wrong. Roudier et al. (2012) showed for the Niamey Region of Niger that in response to forecasts, farmers were able to choose between millet cultivars, between levels of fertilisation, and between sowing dates. Seasonal forecasts improved farmers' situations in bad years and farmers benefited from improved incomes even when the forecast was not perfect. They concluded that improving forecasting systems by including the prediction of onset and cessation of rainfall would be of great value. In a case study in the savannah zone of Ghana, both men and women farmers reported that their use of weather forecasts over the radio is only occasional and they trust and rely on traditional methods (Naab

and Koranteng 2012). The IDRC/DFID programme showed through PAR how weather forecasting, taking into consideration indigenous knowledge, can be successfully used to strengthen farmers' adaptive capacity to climate change (CCAA 2012).

13. *Insurance*: Ngigi (2009) reported very little provision of formal insurance for smallholders in West Africa, but the situation seems to be improving. In Senegal, for example, the government has set up a national fund for agricultural insurance supporting 50 % of the premium. Index-based insurance (which correlates strongly with farmers' production outcomes) can serve as a buffer against climate extremes (Ngigi 2009). Muamba and Ulimwengu (2010) studied the viability of rainfall insurance in 12 districts in the northern region of Ghana for maize producers through a mathematical programming approach. They concluded that rainfall insurance may not work in all districts but may be satisfactory in districts which exhibit a positive correlation coefficient between maize yield loss and indemnity payments; and that rainfall may not be an ideal index for losses, and indexes such as area yield or remote-sensed vegetation may perform better in the design of optimal crop insurance. Although there is a need for further studies to find the most appropriate index-based insurance at community levels, an index-based insurance scheme is up and running. Some smallholder farmers in Ghana have been able to insure their crops against climatic risk through the Ghana Agricultural Insurance Programme (GAIP). At the start of the growing season, farmers pay GAIP a tenth of their cultivation expenses. A period of 12 consecutive days without rain triggers compensation payments to farmers. This insurance scheme is based on data collected daily from 19 automatic weather stations on wind, rainfall, humidity, and temperature. During the first year of implementation 136 farmers were compensated (Spore 2013).

    In summary, there is evidence of the availability, through research and development, in West Africa of several options for strengthening elements of the adaptive capacity and supporting crop farming, at least in the short to medium term, of smallholder farmers. These options are components of a climate-smart agriculture. How well they will work in the long term as climate change continues is uncertain. The research agenda and products of the national agricultural research and extension systems (NARES), CGIAR centres in West Africa, and other research organisations, although initially not intended to respond to climate change adaptation per se, are relevant to some of the short-to medium-term needs expressed in the NAPAs and National Communications.

Documented Adaptation by Crop Farmers

Research has been conducted in West Africa, which provides evidence of adaptation to climate change and/or adoption of recommended adaptation options by farmers. This adoption is a reflection of the realities of climate change and variability on the ground and the ability of farmers to make informed choices from a

Table 5 Some adaptation strategies to seasonal forecasts reported by farmers

Country	Adaptation strategy
Nigeria	Change crop types; reduce herd size; change grazing methods, change planting time; relocate
Burkina Faso	Plant short duration crops/varieties; plant drought-tolerant crops/varieties; use or do not use fertilisers; store/sell grain stocks; orient furrows across slope; acquire capital to purchase inputs; ration food

Source: Adapted from Roudier et al. (2012)

range of available options. Surveys or case studies of countries in West Africa have documented the following: shallow and hand dug wells to supplement the shortfall in water in the dry season (Ngigi 2009); soil moisture improvement technologies including zaï, half-moons, and mulching (Ngigi 2009; Nkonya et al. 2011); irrigation, drainage, and lowland cultivation (Adebayo et al. 2011; Nkonya et al. 2011; Zorom et al. 2013); adjustment of planting dates (Adebayo et al. 2011; Nkonya et al. 2011); agroforestry and crop rotation (Ngigi 2009; Adebayo et al. 2011); rainwater harvesting, collection of rainwater from zinc roofs for storage in tanks, and local earthenwares, bunds, contour bunds, dugouts, and small reservoirs (Panyan et al. 2011; Zorom et al. 2013); fertiliser and manure use (Nkonya et al. 2011; Zorom et al. 2013); diversification in the form of introducing new crops and livelihood changes (Nkonya et al. 2011); integration of livestock with crops and engagement in off-farm activities, for example, gold mining (Ngigi 2009); protection and planting of trees (Nkonya et al. 2011); migration of farmers in wetter areas (Ngigi 2009); and use of weather forecasts and early and/or drought-tolerant crop varieties (Nkonya et al. 2011; Roudier et al. 2012). Concerning weather forecasts, Roudier et al. (2012) cited examples of adaptation to weather forecasts reported by farmers (Table 5).

Gender-disaggregated research data are scarce, but Naab and Koranteng (2012) found that in the same village in the Upper West Region, in the savannah of Ghana, men reported that they used planting of trees, intercropping, crop rotation, and cultivation of lowlands to adapt to climate change and women reported tree planting, dry season vegetable gardening, compost and farmyard manure use, not burning bush and crop residues, and application of crop residues as adaptation/coping strategies.

The relationship of adoption to agroecologies and the determinants of adoption have been studied: thus, Adebayo et al. (2011) grouped technologies adopted by farmers in southwestern Nigeria in response to climate change in terms of agroecologies. They found that in swamps, the order of adoption was first constructed of drainages, being much greater than channelisation of beds, which was in turn greater than adjustment of planting date. In the forest zone, adoption of irrigation was much greater than afforestation, which was greater than use of fadamas (valley bottoms/lowlands). In the savannah zone 'no adoption' was much greater than irrigation, which was greater than adjustment of planting date.

Key determinants of adoption of drought-tolerant maize in the Bono State of northeastern Nigeria, in the northern Guinea savannah zone of West Africa, were shown to be access to technology, complementary inputs, extension services, and climate change information (Tambo and Abdoulaye 2012). They also found that off-farm income and wealth status of a household were important in adoption, implying that it would be difficult for resource-poor farmers to adopt adaptation technologies. Farmers identified costs of the technology package, in particular fertiliser inputs, as major constraints to adoption. Nkonya et al. (2011) reported that in the semi-arid zone of Niger, female-headed households were less likely to respond to climate change than male-headed, whereas in the same zone in Nigeria gender did not have a significant effect. Both in Niger and Nigeria having nonfarm activities reduced the likelihood to respond to climate change and there was a positive association between distance to markets and response to climate change. This suggests that marketing opportunities provide stimulus for maintaining or increasing productivity.

A word of caution was raised by Mertz et al. (2009), who in a study of the Eastern Saloum, Senegal, concluded that communities are highly aware of climate issues, but climate narratives are likely to influence responses when questions mention climate change. Changes in land use and livelihoods in the study area are driven by adaptation to a wide range of risk factors of which climate, though important, appeared not to be the most important. The wider applicability of this conclusion to savannah and forest communities in West Africa is untested.

Lessons from Adaptation Projects and Interventions in Crop Farming

A consistent lesson reported from climate adaptation research is that although climate change is a source of significant stress (and perhaps opportunities), it is only one factor among many with which smallholders have to contend. Several adaptation projects have been conducted or are ongoing in West Africa. Lessons reported by a selection of projects and successful interventions (Nkem et al. 2011; BNRCC 2012; CCAA 2012; Mapfumo et al. 2013) are grouped in Table 6 in terms of implementation, gender, weather, local knowledge and participation, partnerships, and institutions and policy makers.

Key Documented Barriers to Adaptation by Crop Farmers

Adoption and assimilation of adaptation strategies and options into national development plans has been slow. The documented barriers include economic capacity, information systems, technology development and dissemination, infrastructure/institutions, sociocultural perspectives, gender issues, environmental issues, extension services, incentives and conflicts among different interest groups, and inadequate policies or lack thereof (Ngigi 2009; Nkem et al. 2011; Nzeadibe et al. 2011).

Table 6 Lessons from adaptation projects and interventions in crop farming

Groups	Lessons
Implementation	• Sufficient time is needed to promote learning and action with full community participation, to enhance local adaptive capacities and strengthen the resilience of communities, and to learn from these actions
Gender	• Women and children are usually the most vulnerable groups and the most affected by climate change impacts • In ensuring awareness and sensitisation to the issues, it is important that all community members, both women and men, agree on and are clear about the process • More work needs to be done to overcome the social and cultural barriers for communities to fully embrace gender equality
Weather, local knowledge, and participation	• Farmers are better able to adapt to climate change and variability when they engage with and apply climate information • Scientific seasonal climate forecast information is mostly supply driven at the national level and does not reflect understanding of user needs • Integrating indigenous knowledge forecasts and scientific seasonal climate forecasts has worked well in many instances but could benefit from further analysis and policy support • Participatory Action Research is necessary to take into account local knowledge to adjust advice and frequency of forecasts to the specific realities of an area or community. Messages in the local languages greatly facilitate uptake • Choosing influential farmers as experimenters can increase uptake of tested soil and water management practices • Participatory technology testing is most effective when farmers are respected and their knowledge considered. In addition, farmers should have ownership of the process of reflection-action-evaluation-planning and its integration into ways of addressing their constraints • Participatory action research provides an entry point for building adaptive capacity of farmers
Partnerships	• Vulnerability assessments, identification of adaptation options, and the implementation of those options often depend on different areas of experience and expertise in order to minimise the risk of failure • Partnerships among relevant institutions including nongovernmental organisations (NGOs) and local communities can strengthen capacity and increase use of seasonal and indigenous forecasts • Project achievements derive largely from the strength and dedication of the entire project team, including the partner organisations and the participating community members with the support of their village heads
Institutions and policymakers	• Institutional barriers to adaptation are more important limitations compared to issues with scientific uncertainties surrounding adaptation options • Involving policy makers at the early stage of a project permits them to appreciate the benefits themselves and help identify resources to sustain useful practices identified through research

Economic Capacity, Information Systems, Technology and Technology Dissemination

Farmers need to have the money to adopt new technology, but smallholders in West Africa are poor, and therefore lack the capacity to adapt. Cost of adaptation packages (including good quality seeds and fertilisers) has been documented as a constraint to adaptation (Adebayo et al. 2011). Farmers can therefore be locked into a vicious cycle of poverty, little use of nutrient inputs, soil mining, and therefore degradation of the environment and increasing vulnerability to climate change.

At the regional level, the African Centre of Meteorological Application for Development (ACMAD) and the Agro-Hydro-Meteorology (AGRHYMET) Regional Centre provide broad information to national partners, but their work is based on inadequate data. The density of meteorological stations in sub-Saharan Africa is one eighth of the minimum recommended by the World Meteorological Organization (Tall 2010). Poor information systems, both at local and national levels to collect, process, and disseminate climate change information and weather forecasts hinder uptake. Poor availability and access to technology and a community's inability to modify the technology adversely affect uptake. It was shown in an earlier section that availability of crop technology for adaptation, at least in the short term, is not a problem; the issue is with regard to accessibility. National extension services are generally weak due to funding and skills constraints.

Infrastructure, Institutions, and Land Tenure

Poor physical infrastructure (irrigation water supply, water management structures, transportation and marketing systems, storage and processing structure, and communication) and inadequate social infrastructure/institutions such as inadequately funded research institutions and unempowered farmers' organisations, cooperatives, and water users' associations are widespread. For example, the Sierra Leone Agricultural Research Institute, with five operating research centres, was allocated approximately US$600,000 in 2013 for nonsalary recurrent expenses, which is 10.6 % of the nonsalary recurrent allocation to the Ministry of Agriculture, Forestry and Food Security (Government of Sierra Leone 2012). Furthermore, funds actually disbursed are sometimes less than funds allocated. With increasing population all over West Africa, access to land in the context of current land tenure systems is becoming very difficult. Poor access to credit for investments and inputs is also linked to the fact that the land under the traditional system cannot be used as collateral for loans. Ngigi (2009) drew attention to how ensuring land tenure for farmers increased water management and irrigated rice production in the Office du Niger, Mali.

Sociocultural Perspectives and Governance Structure

Two case studies conducted in Burkina Faso provide examples of how sociocultural factors can influence adaptation. It was shown that weather information necessary for adaptation sometimes circulates selectively; in a village in Burkina Faso, women were excluded and in two villages 'lower caste families' and families opposed to the village leader and herders residing at the edges of the villages did not receive forecast information (Roncoli et al. 2001). Nielsen and Reenberg (2010) studied two ethnic groups, the Fulbe and Rimaiibe, in the village of Bidi 2, northern Burkina Faso. They found that although the Fulbe were aware of the potential benefits of livelihood diversification – labour migration, development work, women's work and gardens – as they daily observed how these strategies of adaptation to climate change benefited the Rimaiibe by providing them with cash for household survival, they were unwilling to fully embrace them because they entail attributes deemed 'non Fulbe'. It is unknown how widespread this behaviour is in Burkina Faso or in West Africa, but it underscores the need for taking local factors into consideration in technology development and policy formulation.

There are vulnerable groups of both genders in rural communities in West Africa; but it is widely recognised that, in general, women are the most disadvantaged. Unequal access to land and water resources, limited involvement of women in water resources management systems, inadequate contribution to decision-making processes, higher illiteracy rates than men, and poor access to credit are all mitigating against innovation and adoption of climate adaptation practices and other agricultural technologies. Weak governance hinders the content of policies, policy formulation process, and implementation at the regional, national, and local levels with regard to climate change and adaptation (Ngigi 2009).

3.3 Agricultural Development and Climate Change Adaptation Policies

3.3.1 Climate Change Considerations in Continental Agriculture Sector Policies

The African Union/New Partnership for Africa's Development (NEPAD) Comprehensive Africa Agriculture Development Programme (CAADP) sets the overall framework and principles on agricultural development in sub-Saharan Africa, intended to be cascaded to the regional and national levels. CAADP contains broad themes of opportunities for investment to reverse the crisis facing African agriculture, which has made the continent import-dependent, 'vulnerable to even small vagaries of climate', and largely reliant on food aid (AU/NEPAD 2003). The 'vagaries of climate and consequent risks' that determine investment is also listed as one of the six challenges to achieving a productive agriculture. 'Land and water management', which is very important for adapting to climate change, is a Pillar of CAADP. In addition, the environmental initiative of NEPAD prioritises climate change as one of its ten programmatic areas.

3.3.2 Agriculture Considerations in Regional Climate Change Policies or Strategies

ECOWAS developed an Environmental Policy (ECOWAS 2008) whose overall objectives are to reverse environmental degradation and depletion of natural resources, ameliorate the quality of the living environment, and conserve biological diversity to ensure a healthy and productive environment. The strategic actions include promoting, monitoring of environmental change, and the prevention of risks by setting up a Regional Center Observatory, combating land degradation, drought and desertification, and sustainable management of coastal, inland, and marine ecosystems. Response to climate change was not one of the actions. Thus, in 2010 a Regional Action Program to Reduce Vulnerability to Climate Change in West Africa (ECOWAS 2009a, b) was adopted. It was agreed at the International Conference for Reduction of Vulnerability to Climate Change of Natural, Economic and Social Systems in West Africa of 2007 in Burkina Faso and the Ministerial Meeting on Climate Change of 2008 in Benin to develop and implement a programme of action to reduce vulnerability of West Africa and Chad to climate change. CILSS, the Economic Commission for Africa (ECA), and ACMAD were mandated to develop the programme.

The regional programme document noted that although urgent priority measures in the NAPAs are worthy of continuation and support, it is also important to complement them with concerted adaptation options at the regional level. The goal of the ECOWAS programme is, at the regional level, to develop the required mechanism, actors, and capacity to provide support to governments and communities as they adapt to climate change. The objectives are: (1) regional institutions are politically, technically, and financially supporting the states in their process to adapt to climate change; (2) national stakeholders in each country are adopting harmonised and coordinated approaches to adapting to climate change; and (3) climate change is mainstreamed into priority regional and multicountry investments, programmes, and projects. The coverage of the 10 development sectors including agriculture (crops and agroforestry) is envisaged, but the extent to which adaptation to climate change in the agricultural sector will be dealt with is not given and presumably will depend on national priorities.

3.3.3 Tradeoffs and Barriers to Mainstreaming Climate Change Adaptation into Agricultural Policy

ECOWAS's regional policy guidelines, the NAPAs (prepared under guidance from UNFCCC) and the policy documents prepared by Nigeria and Ghana all indicate that policy documents on climate change are separate from agricultural development policies and other plans/strategies. However, in general, the agricultural development policies/plans recognise directly or indirectly the need for responding to climate change without tying productivity targets to the projections of how climate change could affect agriculture.

There are benefits and disadvantages to mainstreaming adaptation to climate change into agricultural policies (ECOWAS 2009a, b). The benefits are: additional policies and their associated bureaucracy to be added to already stretched government institutions are not required; it does not increase duplication, potential incompatibilities, or conflicts among policies and agencies; adaptation initiatives fall within policies that are already established in agencies with expertise, experience, and stakeholder connections in policymaking; it focuses more directly on practical adaptation and mitigation initiatives than on climate monitoring, models, and predictions. The disadvantages are that many programmes and agencies have to be engaged; and it is difficult to distinguish accomplishments in climate change adaptation from other development activities responding to various stresses.

The United Nations Environment and Development Programmes (UNEP and UNDP) Climate Change and Development Project—Adapting by Reducing Vulnerability in Senegal, Togo, Benin and Ghana reported inadequate knowledge on climate change risks, level of vulnerability, and adaptation options at the local level; inadequate institutional capacity to address the challenges posed by climate change at the local level; weak partnership between central and local government; and lack of proactive, targeted, and cost-effective strategy that increases the long-term resilience of the population as barriers to mainstreaming adaptation into national development frameworks (Nkem et al. 2011).

3.3.4 Key Arguments for Policy on Adaptation to Climate Change

Technical interventions cannot be effective and sustainable without supportive governance measures concerning policy and legal issues (Ngigi 2009). Incentives and flexibility are enhanced by good governance, policy, and institutional responses. The benefits of adaptation to climate change are more local compared to mitigation whose benefits are more global; hence the need for national and local policies dealing with adaptation is crucial.

In Mali, a comprehensive macroeconomic policy and institutional reforms (including provision of short- and medium-term credit to farmers and access to land) have turned irrigated agriculture into a profitable enterprise, sustaining livelihoods of farmers and improving the national economy (Aw and Diemer 2005). Also, a case study in the semi-arid zone of Nigeria and Niger concluded that the support of the Nigerian government over several years for irrigation development and more recently small-scale irrigation increased agricultural production and reduced production risks in the drier northern states (Nkonya et al. 2011). Although the irrigation programmes were not implemented as part of an adaptation to climate change programme, they helped farmers adapt to climate change. Furthermore, the adoption rate by farmers of fertilisers was relatively high because of the government's substantial fertiliser subsidy and promotion of fertilisers for a long time. For Niger, the granting to users of the right to own and benefit from trees on their farms, through the Rural Code, contributed to the greening of the Sahel.

3.3.5 Key Barriers to Uptake of Research and Successful Policy Implementation

The linkage between research and policy is weak, and research therefore does not adequately inform policy. The reasons for this are many: very conscious of maintaining their objectivity, researchers traditionally get uncomfortable about close contacts with policy makers. Decision makers on their side may think of researchers as too academic and impractical or their findings not used for decision making. Other obstacles are the perceived uncertainties surrounding climate change and modelling (e.g., there is some inconsistency in the predictions made by GCMs) and the short-term perspectives of politicians related to their tenure in office. The time lag between the time the research is conducted and the findings are made known is very long and the presentation often too technical; sometimes outputs of research do not even reach national policy makers, natural resource managers, or farmers (Huq and Reid 2005). What approach in research-policy dialogue works best and under which situation is unknown. Policy making in West Africa, even when evidence based, is generally linear. IDS (2011) argues that the policy process is not linear where researchers' roles are limited to providing scientific evidence at the end of the research process. The policy process is a disputed space, a complex mesh of competing interests and negotiations, in which power and politics are central.

3.4 Gaps in Climate Change Adaptation Research and Policy in the Agricultural Sector

Several studies undertaken in West Africa on adaptation research and policy reveal incomplete detailed technical knowledge of how to adapt sustainably to climate change in agriculture and weakness in policy formulation and implementation (Thornton et al. 2007; Ngigi 2009; FAO 2008, 2010b; Sultan et al. 2010; CGIAR 2011).

3.4.1 Key Research Gaps and Challenges

Crops

Across the region, there is limited or inadequate knowledge in several thematic areas such as how in response to climate change, farmers will shift to different crops, affecting feeding habits, nutrition, and cultural norms; on conservation agriculture; on adaptation at the watershed level; and on the productivity of biofuel crops in water-stressed conditions. There are no improved varieties of Jatropha that are being promoted in Mali and Ghana as a biofuel crop. There has been little research on climate change and tree crops/agroforestry.

Cross-Cutting Gaps

The incomplete understanding of the wide-ranging processes underlying the performance of markets, ecosystems, and human behaviour contributes to the uncertainties associated with modelling the impacts of climate change on the agricultural sector (Nelson et al. 2013). There is little or no routinely reliable method on the predictability of the onset of the rainy season and intraseasonal variability and how to make weather forecasting work best for smallholders. There is also limited knowledge on the applicability of index-based insurance to smallholder situations. Other areas of limited or inadequate knowledge are: adaptation through control of plant diseases; thresholds in natural systems beyond which adaptation may be very difficult or impossible; assessment of the effectiveness of adaptation options and understanding likely adoption rates, tradeoffs, costs, and returns of adaptation strategies; effective ways of communicating climate change information and its consequences on livelihoods and the environment; women's strategic interests (access to land and credit, decision-making power, etc.) in responding to climate change and variability; and relative benefits of promoting regional versus global trade for crop products.

3.4.2 Key Policy Gaps and Challenges

The national policies in place in West Africa (specifically Nigeria, Ghana, and Senegal) are generally more robust for technological practices compared to non-technical risk management, for example, trade. International trade is expected to play a critical role in adaptation and would itself be affected by climate change but there is little understanding of how all of these will play out and what the appropriate policies should look like. That climate change and adaptation are not always mentioned in agricultural development policies and strategies is an important weakness. Also, some policies to the benefit of one sector have been to the detriment of another.

There are inadequate policies or lack of policies in several areas: dry season reserves and livestock corridors from encroachment by crop farmers, investors, and national parks; transboundary control of water resources; strengthening climate communication and information networks to improve timely delivery of weather information; built-in capacity for flexible policies that continuously respond to changes; collaborative learning processes and understanding of the context in which decisions are made and the capacity of decision makers to change; gender imbalance in access to factors of production; mainstreaming gender into all climate adaptation policies and strategies; and weak institutional capacity to generate and utilise adaptation technologies.

3.4.3 Options, Spaces, and Opportunities for Improved Uptake of Research

Policy spaces are places, areas, locations, and gaps where policy can be influenced. Examples of policy spaces and tools for policy engagement are informal expert consultations through national consultative groups used effectively to widen debate and common understanding on topics such as food insecurity and climate change and climate-smart agriculture, and creating informal spaces within otherwise formal processes (IDS 2011). Through its interaction with the Sectorial Permanent du Plan d'Action Pour la Gestion Intégrée des Resources en Eau (SP/PAGIRE) in Burkina Faso and the Water Research Commission (WRC) in Ghana, the CGIAR Challenge Program on Water and Food (CPWF) is promoting a 'visionary team' (mediators) to guide project activities and ensure uptake of the programme (Aduna 2011). The fact that researchers, trained in the conventional way of investigation and reporting, are becoming familiar with participatory action research and donors are keen to fund PAR are all opportunities for bridging the gap.

4 Central Africa

Sub-Saharan Africa is often cited as one of the world's most vulnerable regions (Slingo et al. 2005) because it maintains the highest proportion of malnourished population, has become more vulnerable, and is now the most exposed region in the world to the effects of climate change (World Bank 2009). A significant portion of its national economies is dependent on agriculture (Benhin 2008; Schlenker and Lobell 2010), and most of its available water resources (85 %) are used for agriculture (Downing et al. 1997). Farming techniques are also relatively primitive, the majority of the continent was already arid, and the smallholder systems that dominate the agricultural landscape have very limited capacity to adapt (Muller et al. 2011).

4.1 Overview of Agriculture in the Central African Region

4.1.1 Climate Challenges in the Region

Africa has experienced a greater warming trend than other regions; about 0.5 °C per century since 1900 (Hulme et al. 2001). In the agricultural sector, the Central African region faces tremendous challenges. A generally low agricultural investment portfolio means that agriculture is extremely sensitive to climatic fluctuations. Agriculture is primarily rainfed, and the onset of rainfall and precipitation levels have become highly variable, with some parts of the region experiencing decreases in annual rainfall that have made it impossible for farmers to be aware of when to plant or where to graze. Wildlife species have also been forced to migrate southward in search of water. Massive floods resulting in soil erosion in dry areas with fewer months of rainfall have made matters worse. New diseases have emerged and minor diseases have developed highly virulent strains. Deforestation is being enhanced by extensive agriculture to increase agricultural production, resulting in massive loss of biodiversity, depletion of water resources, and extensive environmental degradation. Lastly, political conflicts have destabilised some countries, adversely affecting food production and making the region extremely vulnerable to climate change. Agriculture is characterised by stagnant yields, land degradation, and recurrent droughts. Without a sound agricultural sector, the Central African region, already facing food insecurity and poor health, is unlikely to develop diversified economies that can cope with the impact of climate change. Consequently, the impact of climate change on agriculture and food security in the region over the next few decades will depend on progress in applied agricultural research and development (IPCC 2007b).

4.2 Review of Climate Change Adaptation Research in the Agriculture Sector in Central Africa

4.2.1 Adaptation of Crop Farming Systems to Climate Change in the Central African Region

In all countries of the region, the crops most affected by climate change are maize, cassava, groundnut, bean, yam, and upland rice, which require climate-smart practices for increased field productivity. Climate-smart crop production practices provide management options to farmers to both adapt to and mitigate climate change (FAO 2010b). Sustainable crop production seeks to reduce reliance on nonrenewable external inputs (e.g., inorganic fertilisers) and capitalise on and enhance natural biological processes (e.g., manures) to improve production in a more environmentally-friendly way which avoids degradation of natural resources. To cope with the challenges of climate change, crop production must adapt through, for instance, good selection of crop varieties, plant breeding, cropping patterns, and ecosystem management approaches, and become resilient to greater frequency and intensity of the changes.

By reducing the use of inorganic fertilisers, avoiding soil compaction or flooding to reduce methane emissions (prominent in paddy rice systems), and sequestering carbon (e.g., planting perennial crops and grass species), crop production can contribute to mitigating climate change by reducing GHG emissions. Because farmers are the primary custodians of knowledge about their environment, agroecosystems, crops, cropping patterns, and local climate patterns, adapting cropping practices and approaches will relate strongly to local farmers' knowledge, requirements, and priorities. Hence, sustainable crop production provides farmers with options for farming sustainably, taking into account the local ecosystem. Integrated approaches – such as crop–livestock systems, rice–fish systems, and agroforestry – diversify food sources and consequently strengthen the resilience of farmers' livelihoods, and also provide opportunities for mitigating climate change.

Climate change impacts on food crop smallholder farming in Central Africa are producing huge economic losses to growers. Although farmers now know that changes have occurred in the amounts of rainfall and onset of rains, changes have been rather abrupt, making nonresilient farming groups in the region face difficulties in adapting to them. Major crops such as sorghum in the drier zones of the region have been most hit, with productivity dwindling massively because of high sensitivity of existing varieties to drought. This has prompted plant breeders to breed short-cycle varieties which are adapted to drought conditions (IRAD 2008). In other countries new varieties of tomatoes, cassava, and groundnuts have also been bred to cope with the changing climatic conditions.

Autonomous Adaptation and Coping Measures

Food security and climate change can be addressed together by transforming agriculture and adopting practices that are climate smart. Unrecognised, a number of production systems considered climate smart are already being used by farmers and food producers in the Central African region to reduce GHG emissions, adapt to climate change, and reduce vulnerability. These include:

(a) *Conservation Agriculture*: CA includes minimal mechanical soil disturbance (i.e., no tillage and direct seeding); maintenance of a mulch of carbon-rich organic matter covering and feeding the soil (e.g., straw and/or other crop residues including cover crops); and rotations or sequences and associations of crops, including trees, which could include nitrogen-fixing legumes. CA offers climate change adaptation and mitigation solutions while improving food security through sustainable production intensification and enhanced productivity of resource use.

(b) *Agroforestry*: The use of trees and shrubs in crop and/or animal production and land management systems is practiced in many forms, including improved fallows, taungya (growing annual agricultural crops during the establishment of a forest plantation), home gardens, growing multipurpose trees and shrubs, boundary planting, farm woodlots, orchards, plantation/crop combinations, shelterbelts, windbreaks, conservation hedges, fodder banks, live fences, trees on pasture, and tree apiculture (FAO 2010b). For instance, *Faidherbia albida*, a tree commonly found in agroforestry systems in the Central African region, thrives on a range of soils and occurs in ecosystems from deserts to wet tropical climates. It fixes nitrogen and has the special feature of reversed leaf phenology, meaning it is dormant and sheds its leaves during the early rainy season and leaves out when the dry season begins (FAO 2010b). This feature makes it compatible with food crop production, because it does not compete for light, nutrients, or water during the rainy season. Farmers have frequently reported significant crop yield increases (6–100 %) for maize, sorghum, millet, cotton, and groundnut when grown in proximity to *Faidherbia*. As with many other agroforestry species, *Faidherbia* tends to increase carbon stocks both aboveground and in the soil and improves soil water retention and nutrient status. With maize being the most widely cropped staple in Central Africa, the potential for adopting this agroforestry system is tremendous.

The study showed that the use of nontimber forest products is one important coping mechanism practiced by farmers to adapt to climate change impacts on agriculture. The use of diversified and multipurpose tree species has been shown to enhance the adaptation of agricultural crops to climate change. By supporting the integration of high-value tree species, a programme in West and Central Africa funded by the International Fund for Agricultural Development (IFAD) helped farmers produce marketable forest products, enabling them to diversify their sources of income, improve their nutritional base, and restore the region's biodiversity (IFAD 2011). The programme led to a gradual reduction in slash-and-burn agriculture and deforestation in these humid tropical areas. To avoid damaging young trees, smallholder farmers have now stopped the practice of burning fields that have been left fallow for several years. Farmers have been trained on agroforestry tree propagation techniques and integration, and now plant trees on their farms. This has significantly reduced the need for them to deplete the forests by cutting down trees. In addition to the benefits of enhanced soil conservation and fertility, the greater number of trees also increases carbon sequestration. Using farmers' indigenous knowledge as well as local community participation in agricultural systems in the region has led not only to the improvement of soil quality (soil structure and soil organic matter), but also efficient water use and soil moisture retention. In some areas crop yields have been substantially increased through the use of such soil conservation and fertility measures (FAO 2011b).

(c) *Exploitation of wetlands*: Another finding was that farmers of the region cope with drought by exploiting wetlands for agricultural production. They adapt to drought conditions by using inland valleys and watersheds, especially in vegetable production and food crop cultivation.
(d) *Other cultural practices*: These include shifting planting dates, modifying cropping patterns and rotations, mulch and cover cropping, crop diversification or the uptake of pre-existing crop varieties, using high-quality seeds and planting materials of adapted varieties, using integrated nutrient management, integrated pest management, integrated weed management, water and irrigation management, landscape-level pollination management, organic agriculture, and land fragmentation of riparian areas and forest land within the agricultural landscape. All of these help to offset some negative impacts of climate change at different levels in the farming systems of Central Africa.

Use of Genetic Resources and Enhancement

Genetic makeup determines a plant's or animal's tolerance to shocks such as temperature extremes, drought, flooding, pests, and diseases. It also regulates the length of growing season/production cycle and the response to inputs such as fertiliser, water, and feed. The preservation of genetic resources of crops and breeds and their wild relatives is therefore fundamental in developing resilience to shocks, improving the efficient use of resources, shortening production cycles and generating higher yields (and the quality and nutritional content) per area of land. Generating varieties and breeds which are tailored to ecosystems and the needs of farmers is crucial. The selection of clones and crop cultivars with tolerance to biotic and abiotic stresses (e.g., drought, high temperatures, flooding, soil aluminium toxicity, high soil acidity, insect pests, and diseases) are providing an opportunity for genetic variation to enhance the improvement and development of new crop varieties which offer hope in adaptation to climate change. National and international research institutes and NGOs in the region are also promoting the use of indigenous and locally adapted crop genotypes and selecting, multiplying, and popularising these crop varieties and landraces adapted to, tolerant of, or resistant to adverse climatic conditions.

Response of Crop Species in Adaptation to Climate Change

The greatest benefits in food-insecure regions such as Central Africa are likely to arise from more expensive adaptation measures, including the development of new crop varieties (which takes a long time) and uptake of costly new technologies such as the expansion of irrigation infrastructure (especially for irrigated rice cultivation). Farmers of the subregion agree that among the roots and tubers, cassava (the basis of the diets of most populations) is the hardest hit, and its field yields and disease resistance have been most affected by climate change. High-yielding cassava varieties which were yielding upwards of 35 tons/ha under on-farm conditions have seen their yields reduced to a bare 15 tons/ha. New diseases including the cassava root rot have developed in synergy with root insects such as the African root and tuber scale (*Stictococcus vayssierei*). African cassava mosaic disease, endemic in the region, has developed more virulent strains such as the Ugandan variant. At the same time, a minor cocoyam leaf spot (caused by *Phytophthora colocasiae*) has turned into a yield-devastating blight for the crop. The severity of maize and sorghum *Striga* has made these crops less productive in the north, leading scientists to produce extra-early maize and sorghum varieties to curb hunger in that agroecological zone. In the forest region, plantain fungal diseases have increased in severity because of progressively heavy precipitation in that ecozone. Maize has been seen to be the most vulnerable cereal, followed by rainfed rice. Groundnut and common bean are the grain legumes most affected by a changing climate in the subregion. All these have seen substantial losses in agricultural production. There is a need to support research in the region to enable farmers to adopt measures and strategies for adaptation of their agriculture to these climate-induced changes.

A recent study showed substantial yield increases for bambara groundnut, soybean, and groundnut, and little or no change and even decreases of maize and sorghum yields, varying according to the climate scenario and the agricultural region in Cameroon. The yields of maize and sorghum are expected to decrease by 14.6 and 39.9 %, respectively, across the whole country. The results also show that the effect of temperature patterns on climate change is much more important than that of precipitation. Findings call for monitoring of climate change/variability and dissemination of information to farmers, to encourage adaptation to climate change (Tingem et al. 2008). Taking the ‘no regrets’ principle in considering specific adaptation strategies for three crops, maize, sorghum, and bambara groundnut, showed that changing sowing dates may be ineffective in counteracting adverse climatic effects because of the narrow rainfall band that strictly determines the timing of farm operations in Cameroon. In contrast, the possibility of developing later maturing new cultivars in some regions proved to be very effective in offsetting adverse impacts, giving the highest increases in productivity under different scenario projections without management changes (Tingem et al. 2009).

Role of National Governments

Governments of the Central African region must recognise that the projected impacts of climate change have to be included and be given a high priority in their countries’ development agendas, because in order to reduce their vulnerability to disasters, planning in land-use systems, natural resource management, and even the design of road, water, and energy infrastructure must be done. This should lead to reform in public policy, development of technological measures, and an adaptation to management systems. In the region, provision of financial resources and willpower from governments will assist in building adaptive capacity and adaptation management, all of which are necessary for adapting the agricultural systems to climate change.

4.3 Agricultural Policies for Climate Change Adaptation

Climate change is viewed as one of the gravest threats to the future of humanity. Debates and commitments relating to climate change in Africa date back to the G8 summit in Gleneagles, Scotland in 2005 (Niang 2007). During that summit, it was noted that Africa was having difficulties in achieving the Millennium Development Goals (MDGs) by 2015. Decisions were made to support the reduction of African countries’ vulnerability to climate change by strengthening the existing institutions and climate centers in Africa through the Global Climate Observing System (GCOS), and a commitment was made by the World Bank to take account of climate risk in its investment portfolio. West Africa, confronted with desertification, has several institutions with clear and distinct mandates on climate change issues, including the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), the Agro-Hydro-Meteorological (AGRHYMET) Regional Centre, the Centre for Medical and Health Research (CERMES), research institutes, universities, and NGOs. In Central Africa, where the chief concerns are linked to climate change as it affects agricultural production, deforestation, depleting water resources, loss of biodiversity, and environmental degradation, subregional institutions are still in gestation. In a summit of the African Union African heads of states were asked to integrate climate change issues into their national development policy agendas, and since then an interest in climate change has begun to develop, especially at the level of the Economic Community of Central African States (Niang 2007). This view was reinforced at a meeting of the Assembly of the African Union in Addis Ababa, Ethiopia, during which a decision was made that specifically urged all of the governments in the region to integrate climate change considerations into development strategies and programmes at national and regional levels and to implement the Plan on Climate Change and Development in Africa.

4.4 Gaps in Climate Change Adaptation Research and Policy in Agriculture in the Central African Region

In the Central African region there are at least five areas of concern reflecting huge gaps in climate change adaptation research, namely: (a) adaptation in forestry, where forest ecosystem goods and services are found to be indispensable in planning adaptation in all other sectors (Nkem et al. 2007); (b) adaptation in agriculture; (c) adaptation in water resources; (d) adaptation in public health; and (e) adaptation in urbanisation. Much work has been done on climate change adaptation in forestry (especially on mitigation efforts and the reduction of GHG emissions resulting from deforestation and forest degradation), and it is here also where international partners have put more emphasis, probably because of the importance of forest resources in the region. But even here, there are still areas of concern, such as the GHGs (fluorocarbons) utilised in the domestic fridges, which are manufactured in developed countries but sold to developing countries.

4.4.1 Gaps in Agricultural Research and Policy

In agricultural research, the main gaps relate to identifying how to tackle climate change scenarios (precipitation, floods, temperature, and drought) on crop farming and making the necessary government policies to implement adaptation. Major gaps in agricultural research are: (a) the adaptation of annual crop (maize, sorghum, millet, and wheat) cultivar responses to drought in drier zones given the shortened water regimes in the Sahel, and the need for new crop varieties required by growers to bring resilience in the agricultural community in that zone; (b) tackling emergent crop diseases in the wake of a changing climate; (c) countering increases in small animal diseases and pests in the forest–savannah transition areas in response to global warming and regional climate change; and (d) addressing fragile, highly depleted soils which are very vulnerable to climate change (Knox et al. 2012). Policies on these issues, accompanied by appropriate funding, need to be made, especially as climate change adaptation studies in agriculture are just beginning to be perceived as high priority issues and unavoidable threats to food security.

4.4.2 Policy Gaps in Climate Change Adaptation

Adaptation policy in the region appears to be low because of the apparent low commitment of governments to support adaptation. As the main stakeholders, governments should be ready to play the major role of rallying all other stakeholders; bring them to the negotiating table so as to make a clear evaluation and identification of adaptation issues and strategies; and fund the adaptation activities. The research results obtained should be transferred to the end-users through appropriate mechanisms and workable stakeholder training.

4.4.3 Research Policy Gaps in the Region

Research policy gaps also exist. Research activities could be formulated, but if not funded, adaptation will not be enhanced. In developed countries industry funds most of the research; in Africa, the main research support comes from governments, making the latter a very important factor in the adaptation development process. Research must therefore undertake the necessary advocacy to attract government funding for its initiatives.

4.4.4 Research and Policy Gaps in the Various Countries of the Region

(a) *Inadequate scientific infrastructure and manpower*: Many national research systems are not sufficiently staffed and do not have the appropriate infrastructure. Because funding is usually inadequate, the governments of the region could pool resources together and establish regional institutions, centers, or laboratories of excellence to serve the countries of the region, especially for complex issues such as climate change. Scientists could also be trained or retrained in climate change research and on current areas including GIS, remote sensing, climate forecasting, monitoring, and evaluation, and these skills could similarly be shared in the region. Unfortunately, because national institutions cannot adequately fund research, many research scientists have resorted to doing consultancies and other things to occupy themselves and make ends meet.

(b) *Improvement of extension systems*: Regional extension systems need to be reinforced. It should also be regional policy to include civil society in the public extension services so as to tap into their competence, willingness, and availability in the dissemination of climate- and adaptation-related results.

5 Southern Africa

There is a growing need for the development of climate change response strategies and policies at different levels, from local to subregional scales, in sub-Saharan Africa. Global scientific inquiries have revealed unequivocal evidence that the world's climate is changing and presenting new challenges to almost all spheres of development, as well as threatening the sustainability of current human livelihood systems (IPCC 2007b; World Bank 2009). Most of the changes in climate have been attributed to anthropogenic factors related to industrialisation and high external input agricultural systems that characterise most of the world's developed nations. Reports of the Intergovernmental Panel on Climate Change demonstrate that although climate change is a global phenomenon, its effects and impacts will be unevenly distributed across the world's geographical regions, ecosystems, and human communities (IPCC 2007b). Empirical research has shown that Africa's farming systems are highly diverse and heterogeneous (Giller et al. 2011b), revealing complexities associated with any efforts to target development solutions. This implies critical challenges for decision makers in formulating relevant climate change response strategies and adaptation policies. It is currently unclear if the research on climate change conducted in Southern Africa in recent years has generated sufficient empirical evidence to inform policymaking processes at the local, national, and regional levels.

5.1 Overview of Agriculture in the Region

5.1.1 The Role of Climate Change Challenges

In its fourth assessment report the IPCC projected that Southern Africa will experience longer dry seasons and increased rainfall uncertainty (IPCC 2007b), and this will demand matching adaptation measures. Overall, an analysis of the IPCC data provides evidence of temperature increases of 0.1–1 °C between 1970 and 2004 in countries that include South Africa, southeast lowveld areas of Zimbabwe, and southern as well as coastal parts of central Mozambique. During the same period, corresponding temperature increases in the rest of Zimbabwe, Malawi, and many parts of Zambia, Botswana, and Namibia averaged between 1 and 2 °C. Such magnitudes of temperature change are anticipated to have a significant influence on the functioning of biological systems including terrestrial and freshwater aquatic ecosystems. An analysis of the IPCC projections (IPCC 2001, 2007a) strongly suggests that Southern Africa will suffer negative effects in three main areas; (1) influence on freshwater resources in lakes and dams; (2) breakdown in the resilience of dominant ecosystems; and (3) influence on productivity patterns of food, fibre, and forest products.

Southern Africa falls within the regions where a decrease of 10–30 % in water availability and runoff from rivers is anticipated by the middle of the twenty-first century. This is likely to increase water scarcity in a region already suffering severe water stress for both agriculture and domestic use. Increased frequency of droughts coupled with warmer temperatures and climate-induced floods is likely to force major changes in land use patterns with a high likelihood of overexploitation of resources drawn from major natural ecosystems (Campbell 1996). The majority of rural communities is poor and depend on natural resource pools derived from forest and aquatic systems, including nontimber forest products. Such disturbances are projected to influence the structure and functioning of ecosystems as ecological interactions and geographical distribution of species are altered. The negative effects of climate change are therefore likely to be exacerbated by human actions, with even greater consequences for biodiversity and ecosystem services as traditional water and food supply systems are also stretched by a growing human population. The need to enhance food production while maintaining the agricultural resource base and the resilience of the agroecosystem will be an increasingly important topic in discussions on the development of the Southern African region in the foreseeable future (Ajayi et al. 2010; Giller et al. 2006).

The IPCC projections suggest that there will be a decrease in growing season length and an expansion of semi-arid and arid zones in the context of agricultural production in Southern Africa. More importantly, localised (specific areas) increases in temperature of 1–2 °C are projected to result in decreased crop productivity, significantly increasing the risk of hunger in many communities (IPCC 2007b). Southern Africa is therefore one of the regions where yields from rainfed agriculture could be reduced by up to 50 % by 2020, potentially heightening prevailing conditions of food insecurity and malnutrition. This calls for adaptation options that may include changes in crop type and cultivars as well as planting times for key crops. However, many of the region's communities are known to be among the world's most vulnerable due to multiple stresses (IPCC 2007a; Casale et al. 2010). For instance, access to improved crop seeds and fertilisers is a major challenge for many smallholder communities in Southern Africa (SADC 2012). The agricultural sector in the region still suffers from lack of access to appropriate information, knowledge, and technologies by different farmers, and this may greatly limit the scope for adaptation.

5.1.2 State of Knowledge on the Implications of Climate Change for Other Key Challenges (and Opportunities) for the Agricultural Sector in the Region

One of the major challenges in rainfed agricultural systems such as those dominating in Southern Africa is the lack of awareness by farmers, agroservice providers, and policy makers about past, current, and future changes in climate and their implications. The summary report targeted to policy makers has already revealed a lack of evidence and good examples from Africa regarding impacts and adaptation options (IPCC 2007b), suggesting a need for deliberately supporting empirical research to address these knowledge gaps. Available findings from empirical research strongly suggest complex interactions and relationships between agriculture and natural resources (including environmental service functions) in driving livelihood systems in both rural and urban environments. The current and potential impacts of climate change and variability on these systems are therefore less clearly understood given the limited knowledge on major variables explaining these complexities. However, findings from the limited research studies available to date provide some insights on potential areas of development where climate change impacts are likely to have ramifications beyond agriculture and in turn constrain adaptation. Such areas include: (1) changes in dynamics of rural–urban interconnections; (2) a shrinking natural resource base and environmental degradation, with poor and declining soil fertility as a critical underlying factor; (3) increased resource use conflicts and breakdown of traditional social safety-net systems within/across communities; (4) diminishing marketing and trading opportunities in agricultural produce and derived industrial products; and (5) land ownership disputes.

Numerous research studies over the years have helped to explain the intimate relationship between environmental resources (or natural resource pools) and livelihoods in many rural systems (Campbell 1996; Kepe 2008) and the interconnections between rural and urban livelihood systems in Southern Africa (Andersson 2002). The architecture of urban development in most Southern African countries has tended to discriminate against women, as formal employment historically favoured men who provided much of the labour force during the colonial past. Arguably, this has precipitated a women-dominated (or at least biased) farm labour force, particularly in smallholder areas. However, the working husbands away in urban areas often make strategic farming decisions for these households. Rural communities are therefore often dependent on such services as information and remittances from family members employed in urban areas (Cavendish 2000), whereas urban communities are often subsidised by rural-based family members and relatives in terms of food provision and sometimes income (Andersson 2001). These social collaborations have tended to provide the much-needed social safety-net mechanisms for coping with multiple stress factors including climatic-induced problems. However, the potential value of these collaborations in supporting climate change adaptation has not been critically assessed in the wake of increasing rural-to-urban migration. Conversely, it may be the lack (or collapse) of such social collaborations that triggers conflicts and heightens vulnerability across the rural urban divide. There is also evidence to suggest that similar social collaborations underpin traditional social safety nets that may have helped to reduce vulnerability of different social groups (e.g., livestock owners versus nonlivestock owners) within smallholder communities (Rufino et al. 2011).

Communities in Southern Africa have long been developing strategies and mechanisms for coping with frequent droughts, seasonal crop failure, and perennial challenges of food insecurity, which are often associated with poor and declining soil fertility. Most of the communities fall back on common natural resource pools during poor cropping seasons (Woittiez et al. 2013), yet emerging evidence from the IPCC suggests dwindling opportunities for communities to rely on these resource regimes as water resources are projected to decline (IPCC 2007a). Although indigenous knowledge regulating the use and sustainable management of these resources has not been given due attention in research and development, there is evidence of significant contribution to household nutrition, food security, and income (Shackleton and Shackleton 2004). Previous studies in the region have revealed that most smallholder communities derive up to 35 % of their annual income (Cavendish 2000), and that poorer households get up to 40 % of their calorie intake during drought years (Woittiez et al. 2013) from common natural resource pools. Kalenga-Saka and Msonthi (1994) found high nutritional values of wild fruits drawn from miombo woodlands in terms of macronutrient elements and energy, and Grivetti and Ogle (2000) found high concentrations of essential micronutrients in a range of fruits from similar environments. High dependence on rangeland products such as fruits and vegetables during times of food scarcity has also been commonly reported elsewhere in Africa (Muller and Almedom 2008). However, the studies have also shown that access to these resources is highly differentiated according to gender, age of household heads, wealth status, and composition of households (Woittiez 2010). Poorer households, who often comprise a high proportion of women-headed families, rely more on the common pool resources and therefore the negative impact of climate change on the natural resource base has strong implications for their livelihoods (Woittiez et al. 2013).

Such studies reveal diverse livelihood benefits derived from forests and rangelands (Kepe 2008). Although social, economic, and political factors often comprise the major factors driving conflicts related to issues of access and distribution of natural resources, it is also apparent that conflicts may arise due to multidimensional and competing resource uses and ownership claims. Such conflicts occur not only within and among communities (e.g., for land and water), but also between people and both domestic animals and wildlife (Giller et al. 2008). There is clear evidence that communities attach value to common natural resource pools (forests, rangelands, etc.) beyond current considerations (Kepe 2008; Shackleton et al. 2001), but it is still unknown how these values are likely to change as relationships and interactions among cropping and natural subsystems are altered in time and space by increasing pressures of climate change and variability. Climate change impacts are exerting additional pressures on an already diminishing natural resource base for most communities, calling for extraordinary adaptable solutions to sustain agricultural productivity and develop new income opportunities for the young and growing populations. This may require new forms of production technologies and institutions as the size and quality of land and environmental resources decline.

5.2 Climate Adaptation Research in the Agricultural Sector

5.2.1 Vulnerability and Adaptation of Crop Farming Systems in the Region

Scientific Evidence for Implications of Climate Change

The IPCC projections of increasing air temperatures in Southern Africa are confirmed by a number of empirical research studies from Malawi, South Africa, and Zimbabwe. Yearly average air temperatures in South Africa were found to increase at a rate of 0.13 °C per decade between 1960 and 2003 (Kruger and Shongwe 2004; Abraha and Savage 2006). However, some of the downscaled models projected temperature increases of 2–3 °C, particularly in the interior of the country (Johnston et al. 2012). In Zimbabwe, Unganai (1996) found an increasing trend in mean maximum temperatures of 0.1 °C per 10-year period between 1933 and 1993, with an overall increase of up to 0.8 °C. However, localised temperatures in areas such as the capital, Harare, increased by up to 1.2 °C over the same period, suggesting uneven distribution of the warming even at local scales. The downscaled models used by Unganai (1996) also predicted that a doubling of atmospheric CO_2 mean air temperature would increase by 2–4 °C. Almost a decade later, Mugabe et al. (2012) used four downscaled global circulation models (GCMs) derived from the IPCC and predicted a 1.5–2 °C increase in annual maximum temperatures for the period up to 2050 in most of the country, based on two of the models (CSIRO and MIROC). One of the other two models suggested a 2.5–3 °C increase for most of the country and a possibility of 3.5 °C in the country's western areas within the same period. Climatic data from Malawi showed that mean and maximum air temperatures increased by 2.3 and 2 %, respectively, between 1970 and 2002, and projections up to 2050 also suggest increased warming. The same GCM models used in South Africa and Zimbabwe predicted increases in air temperature of 1–1.5 °C for the northernmost parts of the country, and 1.5–2 °C for the rest of the country (Saka et al. 2012). Although the predicted temperatures vary with geographic areas within countries and also with the specific model used to make the projection, the bottom line is that all models predict a significant warming in the region. This is already consistent with observed patterns from historical field data analysed in each of the countries.

The observed and projected increases in air temperatures have generally been linked to a significant decrease in rainfall in Southern Africa. Unganai (1996) analysed long-term rainfall figures between 1900 and 1993 and concluded that there was a 10 % decline in rainfall over the period. However, the major challenge for cropping systems is likely to come from deteriorating quality of rainfall seasons. A critical analysis of rainfall data from over 40 different stations in Zimbabwe revealed no changes in total annual rainfall, but rather highly significant increases in within-season variability (Mazvimavi 2010). This is confirmed by an emerging body of empirical research suggesting that critical challenges for cropping systems will arise more from increased intraseasonal variability in rainfall rather than the mere total amount received per season (Rurinda et al. 2012). Episodes of floods characterised sometimes by a whole seasonal total received within a single month, followed by conditions of drought within the same season, have been common in Southern Africa.

Several studies have revealed that a combination of increased rainfall variability and increasing ambient air temperatures will in turn cause a significant decline in yields of major staple crops, particularly maize (Makadho 1996; Phillips et al. 1998; Kiker 2002; Dixon et al. 2003). Most of the regional studies have therefore used simulation modeling to evaluate the potential effects of projected rainfall variability in the production of major crops, particularly the staple maize that has a strong bearing on food security. In South Africa, each 1 % decline in rainfall is predicted to cause a 1.1 % decline in maize and a 0.5 % decline in winter wheat production (Bilgnaut et al. 2009). Gbetibouo and Hassan (2005) also predicted reduced yields for a variety of crops including maize, wheat, sorghum, sugarcane, groundnut, sunflower, and soybean due to increased rainfall variability and warmer ambient temperatures. Taking advantage of a wide network of field trials by international and national research networks across Africa, Lobell et al. (2011) used a dataset of more than 20,000 historical maize trials in combination with daily weather data and showed that for each degree day spent above 30 °C final maize yield was reduced by 1 % under optimal rainfed conditions, and by 1.7 % under drought conditions. Furthermore, maize yields are projected to decline by up to 20 % in the next 50 years in Malawi (Ibrahim and Alex 2008; Lobell et al. 2008), and by 10–57 % by 2080 in Zimbabwe mainly due to increased rainfall variability (Fischer et al. 2005; Lobell et al. 2008). A revelation from these various studies is that the highest losses in production will be in areas traditionally considered to be of high agricultural potential, with serious implications for an already food-insecure region. Major losses in production of staple cereals will be due to a rainfall-induced shrinkage in areas suitable for production: that is, the loss of current high potential agroecologies.

Researchers have also used different simulation models to evaluate the implication of the IPCC-based projections (mainly SCIRO and MIROC models). For example, in South Africa, the Decision Support System for Agro-technology Transfer (DSSAT) crop model projected significant maize yield reductions in the current medium to high potential areas by 2050 in relation to the 2000 yield levels (Johnston et al. 2012). Yield increases were, however, projected for some of the country's provinces that include Northwest and areas that are currently considered too cold for maize production in the Free State and Eastern Cape provinces. On the other hand, significant wheat yield increases were projected for the Free State and Mpumalanga provinces (ibid). Using the IMPACT global model for food and agriculture, the area suitable for maize production in South Africa was projected to decline by 25 % between 2010 and 2050, raising concern that the country could become a net importer of maize if no countermeasures are taken. The model, however, showed that sugarcane was the most resilient crop and showed potential for increased yield across large areas in the country (ibid). Similar work in Malawi using DSSAT showed that most of the central and northern regions of the country will witness 5–25 % increase in maize yields in the period to 2050, whereas the southern region will have large areas facing threats of a 5–25 % yield decline (Saka et al. 2012). However, the areas with a potential for more than 25 % maize yield increase were mainly found in the western areas of the country's southern region. Over the same period, the IMPACT model projected no significant changes in areas grown to maize, but a significant decrease in area under cassava, causing a decline in total production despite prospects of a 50 % increase in yield for the crop. There is therefore a high probability that the country will be a net importer of cassava within the 40-year period under consideration. The model, however, projected a doubling of cotton production due to increased yields, although the land shortage is expected to limit any possible expansion in the cotton production area (Saka et al. 2012). In Zimbabwe, similar DSSAT projections based on SCIRO and MIROC models produced inconsistent results on both maize and sorghum yields. With SCIRO, significant areas in the country were projected to suffer a 5–25 % maize yield loss for the period up to 2050, and many areas were expected to witness a 5–25 % increase in yields under the MIROC scenario (Mugabe et al. 2012). Using the CERES-Maize mode in earlier studies, Makadho (1996) concluded that maize production would become an unacceptably riskier agricultural activity for most smallholder farmers in Zimbabwe mainly due high ambient temperatures triggering moisture stress during grain filling. These findings and projections suggest new challenges in managing cropping systems in the future, and have a bearing on potential adaptation options to reduce vulnerability of the cropping subsector in agriculture given the multiple challenges that farmers face.

The foregoing discussion shows the value of modeling in informing future options for climate change adaptation in agriculture, however, it also reveals the glaring knowledge gaps arising from lack of field data on how farmers' current decision-making process may or may not influence the projected outcomes. For example, analysis of interseasonal rainfall variability (Tadross et al. 2005) and intraseasonal rainfall patterns (Tadross et al. 2009) in Southern Africa highlight major challenges of supporting farmers' strategic (long-term), tactical (between seasons), and operational (within season) decisions to minimize/avoid risk or take advantage of any emerging opportunities at local scales. Tadross et al. (2009) projected an increase in mean length of dry spells and a reduction in rainy day frequency in Southern Africa, making farmer choices of planting dates and selection of crop types/varieties critical. The study suggested that early planting may not necessarily be a solution in certain seasons due to prolonged dry spells, yet late planting may also render crops susceptible to diseases and pest outbreaks induced by the late rains. Studies by Tadross et al. (2005) provide insights on how improved understanding of climatic factors controlling critical seasonal rainfall events such as onset and cessation could improve targeting of adaptation options. Decision-making processes for many in Southern Africa, particularly the smallholders in Malawi and Zimbabwe, are undermined by numerous constraints that include lack of timely access to affordable agricultural inputs, volatile output markets, lack of access to climate information, and lack of access to land and improved production technologies. These factors add to the complexity problems defining the scope for the vulnerability of farming households drawing livelihoods primarily from rainfed cropping systems.

Causes of Vulnerability

As noted above, the definition, and therefore conceptual understanding, of the term 'vulnerability' is often different within and among different groups of practitioners in research and development (Casale et al. 2010; Miller et al. 2010). However, there is a general consensus that farmers in Southern Africa and other parts of sub-Saharan Africa are exposed to different stress factors associated with global environmental (e.g., climate change), economic, and sociopolitical change processes, and that the response capacities of these communities are limited. Agriculture accounts for the livelihoods of the majority of Southern Africa's population, either directly or indirectly through employment in agro-based industries. One can argue that the major causes of vulnerability to climate change and variability in the region are inherent in the very traditional problems known to constrain agricultural systems, with the emerging impacts of climatic change presenting a new context for interpretation of these challenges. Farmers in the region, as elsewhere in Africa, are often faced with multiple stress factors that in effect can define the complex interactions underpinning their adaptive capacity (O'Brien et al. 2009; Casale et al. 2010).

There are more commonalities than differences in the major causes of vulnerability to climate change on households and communities in many Southern African countries. These can be classified as outlined below, and the multiplicity of stress factors defining the context of the adaptive capacity of diverse communities against the effects of climate change and variability is also explained.

1. *High dependence on climate-sensitive crop production systems*: The predominantly maize-based (including other cereals and leguminous crops) and rainfed cropping systems of Southern Africa are dependent on season quality on a year-to-year basis, and susceptible to weather extremes of droughts, floods, storms, and extreme temperatures (Dixon et al. 2003; Unganai and Murwira 2010). For example, any negative effects of climatic factors will affect over two thirds of Zimbabwe's rural population who live directly on proceeds from agriculture. In Malawi, about 85 % of the population (51 % of whom are women) are based in rural areas where they depend on rainfed crop production (Government of Malawi 2002). South Africa also presents a good example of contrasting scenarios showing how the heavy dependence on climate-sensitive agricultural systems may be a major source of vulnerability. The Western Cape and Gauteng provinces, which have high levels of infrastructure development, high literacy rates, and low shares of agriculture in total GDP, are relatively low on the vulnerability index. In contrast, the highly vulnerable regions of Limpopo, KwaZulu Natal, and the Eastern Cape are characterized by densely populated rural areas, large numbers of small-scale farmers, and high dependency on rainfed agriculture (Hachigonta et al. 2013). More than 70 % of the South Africa's poor population resides in rural and informal settlements where their livelihoods are dependent primarily on crop production. Overall, the region's overdependence on maize may in itself be a source of vulnerability for millions of people, although this may also present opportunities to draw on technology advancement in crop improvement and management of crop interactions that involve maize. During the past decade, researchers have begun to explore mechanisms for getting smallholder farmers out of the 'maize poverty trap' (Nyikahadzoi et al. 2012; Mapfumo 2009, 2011). A major revelation from this research is that: unless there is sufficient maize on the market, communities will continue to grow the staple crop despite the high rates of production failure. Intensification of the

maize-based systems are therefore considered a pathway to diversification (out of the maize trap) into alternative high-value crops, but this calls for supporting policies on intensification and diversification (Mapfumo 2009).

2. *Poor and declining soil productivity*: Granite-derived soils dominant in many parts of Southern Africa present some of the world's most challenging soils in terms of their inherently low nutrient supply capacity, low soil organic carbon contents, and poor water retention capacity (Mapfumo and Giller 2001; Mafongoya et al. 2006). Poor soil fertility is one of Africa's major developmental challenges (Sanchez et al. 1997; Bationo 2004). The poor and declining soil fertility under maize monocropping inevitably results in a diminishing land quality with several concomitant externalities including agricultural extensification (Mapfumo 2009) and conflicts related to access to land resources (Rukuni et al. 2006; Lahiff 2007). Pressure on existing land resources due to low use of external nutrient inputs resulted in alarming rates of nutrient mining, declining crop yields, and accelerating land degradation as farmers encroach into marginal and fragile lands for cultivation (Stoorvogel and Smaling 1998; Mtambanengwe and Mapfumo 2005). A combination of unproductive soils, poor access to fertilisers and alternative nutrient resources, and increased climate variability is a recipe for absolute disaster for crop production in Southern Africa.
3. *Land degradation and a diminishing natural resource base*: Low productivity levels on croplands often result in annual food deficits at household and community scales (FAO 2010b; Nyikahadzoi et al. 2012), leaving many households to rely on food aid and/or food gathering from common resource pools such as forests, woodlands, and rangelands (Kepe 2008). However, increasing population pressure and a general decline in productivity and size of these common lands have increasingly contributed to land degradation and desertification. For instance, between 1990 and 2010 Malawi lost about 17 % of its forest cover to agricultural expansion, growth of human settlements, and harvesting of domestic fuel wood against low levels of reforestation (FAO 2011c). Poor performance of cropping systems due to climate change will, therefore, not only increase the threats of land degradation, but also undermine the provision of ecosystem services that have traditionally supported livelihoods of many poor households (Kazombo-Phiri 2005; Davies et al. 2010).

In South Africa, the most sensitive regions to climate change are Limpopo, KwaZulu Natal, and the Eastern Cape, because of severe land degradation and reduced natural production capacity. According to Meadows and Hoffman (2002), the Eastern Cape, KwaZulu Natal, and Limpopo possess a combination of physical and socioeconomic factors (both contemporary and historical) that have led to significant and in some cases irreversible, levels of deterioration in the rural environment. The least sensitive regions are the Western Cape, Gauteng, and Free State. A common feature of these regions is that they have a low percentage of subsistence farmers and have the least populated rural areas. Research findings from different countries indicate that smallholder communities in Southern Africa strongly rely on natural resource pools to sustain their livelihoods during drought years or poor cropping seasons (Mapedza et al. 2003;

Frost et al. 2007). Any threats on this resource base due to the negative impacts of climate change will therefore render many households even more vulnerable (Woittiez 2010).

4. *Lack of timely access to crop production inputs and to output markets*: Numerous studies have shown how poor access to crop inputs such as seeds, fertilisers, herbicides, and equipment has remained a perennial problem for the majority of predominantly smallholder farmers in Southern Africa (Kazombo-Phiri 2005; Government of Malawi 2008; Mtambanengwe and Mapfumo 2009; SADC 2012). Smallholder cropping systems, upon which most of the vulnerable communities depend, have mainly been centered on a subsistence mode of production in which endogenous input components are maximised while external inputs are minimised. Many of the farmers, by design, therefore live beyond the reach of markets, yet agricultural development policies are hinged on the principles of (assumed) market participation. Transformation of these subsistence farms into commercially-oriented production systems driven by market objectives (Delgado 1999) therefore effectively demands structural and process changes in knowledge systems, technology development and delivery, institutions, and policies.

   Climate change and variability exert further demands for such transformations, bringing to the fore questions on potential links between vulnerability and functioning (or failures) of agricultural markets at different scales. The rise of smallholder agriculture in post-independent Zimbabwe (before the recent socio-economic and political crisis) (Rukuni et al. 2006), and experiences from Malawi's recent subsidy programme (Dorward and Chirwa 2011) present some key lessons on the value of input–output market access. However, such efforts to increase productivity and commercialise smallholder agriculture have also increased the necessity for external input use, with disproportionate livelihood effects against poorer households and communities in remote areas (Nyikahadzoi et al. 2012; Mapfumo et al. 2013). Due to increased rainfall variability, use of purchasing crop inputs has not only become riskier, but also critically dependent on timing of operational decisions by farmers. There is evidence that farmers with better access to seasonal climate forecasts are better able to make appropriate farming decisions at the farm level and get better harvests (Patt et al. 2005). However, lack of access to inputs often remains an overriding constraint (Patt et al. 2005; Mapfumo et al. 2013). Development of models for supporting access and efficient use of agricultural inputs by diverse categories of farmers and supporting their timely responses to climate forecasts is therefore a major challenge for development researchers and practitioners in their planning of adaptation interventions. Empirical evidence is critically lacking on how timely access to agricultural inputs and output markets can reduce or heighten vulnerability of farming communities under current and future changes in climate change.

5. *Lack of access to information and knowledge*: One major cause of vulnerability in the agricultural sector is the lack of access to agricultural information and knowledge of farmers and local-level service providers (e.g., local extension agents) on climate forecasts, early warning systems, improved agricultural tech-

nologies and practices, and available options for adaptation. The limited information accessed in most African rural communities has also tended to discriminate against women and socially disadvantaged sections of local societies. Farmers depend more on their indigenous (local) knowledge systems and own social networks than conventional scientific knowledge systems for decision making (Nyong et al. 2007; Mapfumo et al. 2010). Farmer decisions on what crops/cultivars to grow, when to plant, as well as when to sell how much of their crops, are therefore not informed by robust (science-based) evidence. However, the value of indigenous knowledge in development (Pawluk et al. 1992; Tanyanyiwa and Chikwanha 2011) is worth recognition. Communities have historically managed to adapt to climate and other environmental stresses, albeit with severe tradeoffs. However, there is a general lack of supporting evidence on how local knowledge systems may or may not be sufficiently understood, or are simply not adequate to inform farmer decisions on sustainable adaptation options to match the magnitude of current and future challenges due to climate change and variability. The nature and magnitude of emerging impacts of climate change are likely to present adaptation demands that are beyond the scope of current local knowledge systems, potentially rendering most of the communities vulnerable. Studies in Zimbabwe and South Africa have shown that farmers have a varied understanding of the major causes of climate change and variability, the current and potential impacts and the need for adaptation suggesting a general lack of equal access to quality, climate, and agricultural information by farmers (Gbetibouo 2008; Dutta 2009; Mtambanengwe et al. 2012). The usefulness of seasonal climate forecasts has often been undermined by lack of credibility, coarseness of scale, and institutional barriers, among other factors (Patt and Gwata 2002).

There is increasing evidence that participatory action research and learning-based research and development approaches enhance access to information/knowledge by farmers in general, and the hitherto marginalised social groups in particular, allowing them to experiment with new technologies and potential adaptation options (Mapfumo et al. 2013). Evaluation of work of SOFECSA in Zimbabwe showed that about 73 % of the farmers preferred interactive farmer-learning platforms to access information on integrated soil fertility management (ISFM) and other agricultural knowledge (Gwandu et al. 2013). In contrast to findings from related studies in the health sector in the region, six farmers' least preferred sources of information included nongovernmental organisations (NGOs), newspapers, and magazines (ibid). There is also evidence suggesting that participatory workshops enhanced use of climate forecast information by farmers (Patt et al. 2005). Lack of access to information renders irrelevant the role of climate early-warning systems, leading to poor preparedness against climatic hazards such as droughts and floods (Unganai and Murwira 2010).

6. *Weakening of local institutions and traditional social safety-net systems*: Farming communities have always coped with multiple stresses as they struggle to sustain their livelihoods, probably accounting for some of the diversity and complexity of agriculture and natural resource management systems that have kept them

going for generations. However, it has become evident that collapsing components of traditional social safety-net systems will likely increase the vulnerability of households and communities. These include the following: (1) breakdown of rural–urban links (Andersson 2002); (2) weakening extended family systems (Casale et al. 2010); and (3) weakening of local institutions that have traditionally supported social collaborations and minimised conflicts to achieve food security (Mapfumo et al. 2013), enhanced management of crop–livestock interactions (Rufino et al. 2011), and regulated use of natural resources such as forestry (Campbell 1996). High-profile development projects that hold high promises (e.g., through environmental conservation and economic benefits), as well as interventions anchored on compliance with donor-driven, but frequently changing buzzwords, have sometimes tended to heighten vulnerability rather than reduce it (Büscher and Mutimukuru 2007; Andersson et al. 2012). Many food aid and relief programmes championed by governments and NGOs have also apparently contributed to erosion of the core values of local social safety nets, often rewarding laziness among communities and weakening their adaptive capacity (Mapfumo et al. 2013). Casale et al. (2010) demonstrated the strong links between external sources of vulnerability such as lack of employment or income and internal sources such as a lack of adequate education that in turn undermine the ability to secure employment. These examples suggest the vulnerability of local institutions to external pressures, which in turn further exposes communities and households to emerging threats of climate change. This also points to the intricate poverty traps that commonly characterise livelihoods of poor communities in developing countries, which if not unravelled and clearly understood in the context of climate change, may instead result in the development of adaptation options that undermine some of the current and future sources of resilience. Dercon (2007) defined a poverty trap as an equilibrium outcome or situation from which one cannot emerge without outside assistance/intervention, and this is often caused by market failures which force farmers into low risk–low return livelihood options (Dercon 2009).

7. *Poor and diminishing capital resource base*: Most households and communities lack the capacity to use or create new off-farm livelihood opportunities due to their current levels of poverty, and it is unlikely that they will be able to respond to additional livelihood pressures, or even take advantage of any opportunities associated with climate change and variability. For instance, Malawi is one of the world's poorest countries, ranking 160 out of 182 countries on the Human Development Index. According to the United Nations Development Programme (UNDP) Human Development Report for 2009, about 74 % of the population still lives below the income poverty line of US$1.25 a day and 90 % below the US$2 a day threshold. The proportion of poor and ultrapoor is highest in rural areas of the southern and northern parts of the country (Ellis et al. 2003; World Bank 2008). Lack of education coupled to physical exclusion from major national economic initiatives due to poor infrastructure present major barriers to climate change adaptation. Communities often lack access to infrastructure such as land, roads, bridges, health and education facilities, and water supply struc-

tures, and are often not the primary beneficiaries of financial services such as microcredit, microinsurance, and microsavings (World Bank 2008; Unganai and Murwira 2010; Government of Zimbabwe 2013). The communities are, therefore, practically trapped, with limited alternative livelihood options outside agriculture for most of the rural communities.

8. *High prevalence of HIV/AIDs, malaria, and other diseases*: Labour productivity in the agricultural sector in Southern Africa has continued to be severely compromised by the scourge of HIV/AIDS. The region has witnessed prevalence rates as high as 25–40 % in many of the countries, creating a great strain on the health delivery system and indirectly affecting another livelihood system (Casale et al. 2010). For example, it is projected that farmers in areas such as the Limpopo, KwaZulu Natal, and the Eastern Cape provinces are unlikely to cope effectively with the potential impact of climate change and variability due to high unemployment and HIV prevalence, and low infrastructure development (Government of South Africa 2004; O'Brien et al. 2009). There are numerous reports of labour constraints as family members spend significant time looking after the sick. Weakening institutional arrangements and social networks have also been found to aggravate the risks associated with loss of labour in the agricultural sector (SADC 2003; Casale et al. 2010).

Options for Strengthening Adaptive Capacity and Supporting Crop Farming-Based Livelihoods

Building adaptive capacity of farming communities in Southern Africa will require a consideration of the diverse farmers' production objectives and resource endowments, and understanding of differential impacts of pending climatic threats on different social groups within and across communities (e.g., women, youth, the elderly, migrant households, and the disabled) in order to appropriately target adaptation options across temporal and spatial scales. Sustainable adaptation options are likely to be those rooted in local knowledge systems and institutions. Strategies for building adaptive capacity in Southern Africa are therefore likely to differ significantly between the large-scale commercial and smallholder sectors. The commercial sector is often characterised by a big capital base and high organisational capacity drawn from their diverse private, corporate, and public ownership structures. Typically, the farmers have larger cash flows and greater diversification, can afford longer planning horizons that take advantage of easy access to credit, and have the capacity to make capital investments and respond to market fluctuations (Thomas et al. 2011). Building their adaptive capacity is therefore likely to involve support mechanisms and policies that enhance technology development and adoption, crop diversification, innovative insurance strategies, and improved financial and risk management (Challinor et al. 2007). In contrast, the smallholder farmers present a more complex scenario because of their heterogeneity (Giller et al. 2011b) and their intricate but resource-constrained livelihood systems. Thus, climate adaptation interventions for smallholder communities will necessarily require fostering capacity for multidimensional responses (sociopolitical, economic, and ecological) and change processes that can transform both agricultural and livelihood systems.

Research studies in Malawi, South Africa, Zambia, and Zimbabwe under the IDRC-DFID funded CCAA programme demonstrated the potential role of a combination of participatory action research (PAR), field-based colearning, participatory technology development approaches, and innovation systems in building the adaptive capacity of different smallholder communities (Twomlow et al. 2008; Majule et al. 2011; Mapfumo et al. 2013). Interventions that significantly influenced social change processes with positive feedback on local institutions were those that enabled access to improved crop types/cultivars and ISFM technologies to address food security concerns and enhanced market participation by farmers (Mapfumo et al. 2013). The interventions demonstrated that PAR and farmer colearning platforms could be coupled to support smallholder farmers to self-mobilise and self-organise for collective action processes that included natural resources management, joint acquisition of agricultural inputs, and marketing of produce. These processes promoted farmer-to-farmer sharing of information and knowledge on ISFM as an adaptation option (Gwandu et al. 2013), and contributed to enhancement of household food self-sufficiency (Nyikahadzoi et al. 2012). Lessons can be drawn from these limited CCAA projects to provide insights on appropriate approaches for building adaptive capacity of the poor and socially disadvantaged (hence more vulnerable) communities. The following are options for crop-based climate change adaptation by smallholder farmers in Malawi, South Africa, and Zimbabwe, as suggested from the various studies:

- Enhancing interactions between planting time and soil fertility management technologies for optimising crop yields under variable rainfall and changing temperature regimes (Crespo et al. 2011; Zinyengere et al. 2011; Mapfumo et al. 2013).
- Promoting timely access to sufficient quantities of quality crop production inputs by farmers in order to enhance the timeliness of farming operations in response to the dictates of prevailing climatic factors. This includes access to fertilisers, seed, herbicides, and farming equipment.
- Improving access to and use of soil, water, and natural resources management technologies, including ISFM technologies (Mafongoya et al. 2006; Mtambanengwe and Mapfumo 2009), conservation agriculture (CA) options (Thierfelder and Wall 2010; Unganai and Murwira 2010), land reclamation/restoration options (e.g., agroforestry and indigenous legume fallows), natural resources management approaches (Mapfumo et al. 2005; Akinnifesi et al. 2008; Nezomba et al. 2010), and integrated water management strategies and techniques (Theu et al. 1996; Nyamangara and Nyagumbo 2010; Maponya and Mpandeli 2012). However, the relative contributions of these options to climate change adaptation processes still require quantification.
- Crop diversification into stress-tolerant crop types and cultivars, including mixes of perennial versus short-cycle cultivars; cash crops versus subsistence crops; root and tuber crops versus staple cereals; and high-yielding crop types and cul-

tivars to take advantage of known windows of favorable climatic conditions (e.g., rainfall and temperature) (Bryan et al. 2009; Dinar et al. 2008). Crop improvement research to develop stress-tolerant crop cultivars is therefore a necessity (Bänziger et al. 2006).
- Switching to more water-efficient crops such as sorghum or millet or changing production entirely from crops to livestock (Kiker 2002; Makadho 1996).
- Integrating stress-tolerant nitrogen-fixing legumes into the cropping systems to enhance soil productivity and improve household nutrition and income (Kasasa et al. 1999; Mpepereki et al. 2000; Waddington and Karingwindi 2001; Mapfumo 2011).
- Development of irrigation infrastructure, including construction of small to medium dams in smallholder farming areas to complement rainwater (Matarira et al. 2004; Bryan et al. 2009).
- Developing mechanisms for enhancing efficiency of resource targeting at field, farm, and community scales (Giller et al. 2006; Tittonell et al. 2012) including options for mineral fertiliser management in response to within-season rainfall patterns, and strategic management of mineral and organic fertiliser combinations (Ncube et al. 2007; Kanonge et al. 2009; Chikowo et al. 2010).

Building research and extension capacity at different levels for technology development, adaptive testing, and participatory monitoring and evaluation of change processes associated with the above options will apparently provide a major avenue for their implementation. The government facilitated the provision of financial aid, credit, insurance, and market incentives to both commercial and subsistence growers which may enable farmers to respond adequately to more challenging cropping environments (Bryan et al. 2009). Other suggested supportive measures include: promotion of diversified employment opportunities, new institutional arrangements, and communal risk-sharing measures to conserve resources (Challinor et al. 2007). Running comprehensive HIV/AIDS programmes can also enhance agricultural labour productivity and redirect resources towards other adaptation options.

Documented Adaptation by Farmers in the Region

Farmers have responded to climate variability through a variety of crop management strategies, although most of these efforts may qualify more as coping than as adaptation strategies. This can be attributed to the fact that farmers have long been living with climatic problems such as droughts, flooding, and within-season rainfall variability, but in recent years the awareness of the magnitude of the problem has been raised. This may therefore explain the limited practical evidence available on adaptation measures that have been pursued by farmers to date. Most of the available examples are notably related to food security, suggesting reactive rather than anticipatory or planned adaptation actions by most farming communities. Tropical Southern Africa is dominated by miombo ecosystems (Campbell 1996) and a number of rural institutions have evolved over time to regulate harvesting and distribution of livelihood benefits among rural communities (Clarke et al. 1996; Shackleton and Shackleton 2004;

Magombo et al. 2012). Smallholder communities have continued to depend on their indigenous knowledge to extract wild fruits and other nontimber forest and rangeland products, particularly during years of poor harvests and drought (Frost et al. 2007; Woittiez 2010). An important source of adaptation from these activities is the evolution of functional community-based natural resource management regimes (Mutimukuru et al. 2006; Roe et al. 2009). This has not only given rise to better opportunities for community mobilisation and organisation towards natural resource conservation, but has also increased consciousness among external stakeholders in development about the value of local institutions and the role they can play in anchoring solutions to emerging environmental threats.

Commonly documented adaptation options employed by farmers directly in management of crop systems include (re)introduction of mixed cropping, and planting of short-season maize varieties and other crops to allow early harvesting and shortening of hunger periods (Stringer et al. 2009). Farmers have also tended to move towards mixed crop–livestock farming (Magombo et al. 2012). Detailed case studies from southern Mozambique (Milgroom and Giller 2013) and northeast Zimbabwe (Rufino et al. 2011) showed how local institutions have evolved out of environmental marginality to yield social collaborations that offer options for adaptation to climate variability by smallholder communities in semi-arid zones. Collaborations that provided for land and draught power (cattle) exchange allowed Mozambican farmers to stagger their plantings and maximise staple cereal production during favorable seasons. In Zimbabwe, such collaborations minimised conflicts between cattle owners and non-owners, allowing for draught power sharing and livestock grazing arrangements that helped offset climate-induced constraints (Rufino et al. 2011). Across most of the region, farmers have also responded by seeking off-farm income opportunities. However, these are often restricted to selling of livestock, domestic assets, and natural resource-derived products, and temporary migration to urban areas or diasporas (Matiya et al. 2011). Table 7 briefly outlines notable research studies that provide relevant insights on adaptation. Notwithstanding the above examples, it was generally evident that concrete examples of adaptation by farmers are critically lacking, whether by their mere absence or by lack of research capacity to identify and document them. A number of adaptation options have been suggested for Southern Africa, including those mentioned above, however, these have largely been at the research level. There are few, if any, studies clearly documenting the adoption of these adaptation options by farmers at scale. Most of the farmers' current responses to climatic shocks have been of a short-term nature, and often punctuated by external but temporal response measures such as food aid and relief programmes.

Lessons from Adaptation Projects and Interventions in the Crop-Farming Sector in the Region

Major lessons on adaptation in Southern Africa are currently limited to few intervention projects, mainly those conducted under the IDRC-DFID funded CCAA (Twomlow et al. 2008; Mapfumo et al. 2010; Majule et al. 2011), DFID (Brown

Table 7 Selected examples of climate change adaptation studies and interventions conducted in Malawi, South Africa, and Zimbabwe

Outline on research based on climate change adaptation studies and their interventions
• Combined use of participatory action research (PAR) and learning centre approaches to revitalise local institutions supporting traditional social safety nets and uptake of integrated soil fertility management (ISFM) technologies and improved agronomic practices (e.g., managing planting date × nutrient management interactions for different crop types and cultivars) by smallholder farming communities in Makoni and Wedza districts of eastern Zimbabwe (Mapfumo et al. 2013). The studies enabled quantification of the contributions of forest and rangeland resources to farmer livelihood during climatic stress (Woittiez et al. 2013)
• Assessment of local climate change adaptation strategies used by farmers in Malawi, such as crop diversification, temporary migration, selling of assets, eating of a wild tuber plant called *Nyika*, small-scale irrigation, and application of organic manures for soil fertility enhancement. These options were promoted at scale by the government, donor community, and civil society in order to build adaptive capacity of communities and resilience of the farming systems against the effects of climate change and variability (Matiya et al. 2011; Magombo et al. 2012). Prioritised interventions included diversification into early maturing and drought-tolerant maize and sorghum varieties (Magombo et al. 2012)
• Initiatives by Practical Action and Lutheran Development Services focused on mainstreaming of climate change adaptation and disaster risk reduction at district, provincial, and national levels through use of community-based approaches so as to empower local communities in decision-making processes in Zimbabwe. This enabled adoption of a livelihoods-centred approach to disaster risk reduction, which marked a policy departure away from postdisaster emergency response (Brown et al. 2012)
• Coping with drought and climate change project in Chiredzi district in southeast Zimbabwe (Government of Zimbabwe/UNDP/GEF 2009; Unganai 2009). Focusing on developing adaptation strategies for smallholder farmers, the project employed principles of participatory decision making, planning, and implementation. One of the key objectives was to promote access and use of medium- to long-term climate forecasts to inform decision-making processes in cropping and water management as well as off-farm activities
• Promotion of conservation agriculture (CA) and related farming practices by various development partners as an adaptation strategy in drought-prone areas. Apart from provision of inputs, smallholder farmers have received new knowledge that enabled them to try new options for adaptation (Mutekwa 2009; Gukurume et al. 2010; Gukurume 2013)
• In South Africa, large-scale commercial farmers have shown promise to adapt through technology development and adoption, crop shifting and diversification, insurance, and improved financial management (Challinor et al. 2007)
• Activities of the Zvishavane Water Projects (Zimbabwe) demonstrated that building on farmers' indigenous knowledge, skills, and experience through soil and water conservation technologies such as water harvesting activities enabled farmers to adapt to harsh climatic conditions prevailing in this area (Mutekwa 2009). Provision of climate forecast information in a language that is understandable to farmers on warnings of poor season, commencement of season, and adequacy of rains also proved a useful entry point for informing decision-making processes (Unganai 2000; Patt et al. 2005)

et al. 2012) and the UNDP/Global Environment Facility (GEF) Coping with Drought and Climate Change Projects7 (Unganai 2009). The CCAA also supported a project that focused on Building Food Security and Social Resilience to HIV/AIDS. Most other climate change projects have generally been exploratory (assessments), and have largely helped to create awareness among communities and development stakeholders, as well as characterising and developing an understanding of the major elements of vulnerability to climate change (Casale et al. 2010; O'Brien et al. 2009). However, these limited development research studies provide valuable insights and lessons to inform future development planning and policy processes for climate change adaptation in crop-based farming systems. The following are some of the key lessons:

- Adaptive testing of emerging practical options for climate change adaptation at scale in the agricultural sector is increasingly necessary, building on available data. Most of the adaptation options suggested for the crop-based farming systems in Southern Africa, such as staggered planting, crop diversification, integrated soil fertility management and irrigation, show promise at experimental scales (Mapfumo et al. 2010; Brown et al. 2012; Rurinda et al. 2013).
- Food insecurity and poverty are in themselves fundamental sources of vulnerability that will severely limit the scope for adaptation. Most smallholder communities typically have limited access to agricultural inputs, soil fertility management technologies, agricultural water, and resource conservation approaches (Mapfumo et al. 2013). This limits their adaptive capacity.
- Farmers, particularly in the smallholder sector, will require technical support to make critical decisions on how to allocate limited resources among crop production, natural resources management, and off-farm employment (Giller et al. 2006; Twomlow et al. 2008). Detailed studies on the tradeoff analysis of these production (livelihood) objectives are necessary to inform planning of adaptation interventions at scale, and to guide adaptation policy processes.
- Climate change adaptation research interventions that employ PAR and field-based farmer learning platforms will likely attract effective participation by diverse social groups from among the farmers, including women and the socially disadvantaged (Mapfumo et al. 2013; Mashavave et al. 2013).
- Increasing farmer access to seasonal climate forecasts coupled with technical agricultural information and access to improved seeds, soil fertility technologies, and crop production practices will strengthen the adaptive capacity of many poor farming communities (Gwandu et al. 2013).
- Investments into integrated approaches to soil fertility management, soil and water conservation techniques, and land reclamation will broaden climate change adaptation options across diverse agroecologies and benefit many rural and urban communities in Southern Africa (Tittonell et al. 2012). This could form a basis for participatory development of 'climate-smart' crop production options.
- Failures of current development interventions to strengthen local institutions and indigenous knowledge value systems may increase current vulnerabilities and compromise future adaptation processes (Roncoli et al. 2011; Mapfumo et al. 2013).
- There is a general absence of large-scale, well-directed research and development programmes to promote locally-adapted crop types/cultivars/varieties that have traditionally supported livelihoods in Southern Africa.

- Based on available studies, it can be inferred that policymakers must create an enabling environment to support adaptation by increasing access to climate information, credit lines, insurance, and markets (input and output) to reach small-scale subsistence farmers with limited resources to confront climate change.

Key Documented Barriers to Adaptation

Major barriers to adaptation processes in Southern Africa revolve around lack of research and development capacity to develop, test, and deliver adaptation processes, as well as the absence of responsive policies that are specifically tailored to meet the emerging climatic challenges. The launching of CCAA was in recognition of the major gap. UNDP (2008) cited limited analytical capability of local personnel to analyze the threats and potential impacts of climate change effectively, so as to develop viable adaptation solutions. Thus, traditional and contemporary agricultural policy frameworks, developed under these inherent deficiencies, are unlikely to deliver adaptation processes without undergoing substantial changes. For example, with no ready access to good quality seasonal climate forecasts (Patt and Gwata 2002; Mtambanengwe et al. 2012) and knowledge on available adaptation options (Kandlinkar and Risbey 2000), farmers will find it difficult to make decisions and plan against future climate stresses. Agroecologies in Southern Africa are generally semi-arid and characterised by poor within-season rainfall distribution (Tadross et al. 2009), yet the majority of farmers have no access to conventional forms of insurance. Farmers' perennial problems with the lack of timely access to crop production inputs, including seed, fertilisers, herbicides, draught power, and equipment (Nyikahadzoi et al. 2012; Mapfumo et al. 2013) have largely been attributed to lack of access to lines of credit (Mano and Nhemachena 2007; Nhemachena and Hassan 2007). This is apparently a major disincentive for farmers to invest in organising their local institutions and capacities to demand new knowledge and adopt improved technologies. Instead, poor institutional arrangements and deterioration of social safety nets (Nyikahadzoi et al. 2012; Mapfumo et al. 2013), against a declining resources base, are sinking farmers deeper into a subsistence mode of production and making them more vulnerable. It is, therefore, essential that fundamentals of sustainable crop production and food self-sufficiency be first addressed, in order to reduce risk of external input use and stimulate innovations towards market participation by farmers.

Another hindrance to crop-based adaptation interventions is lack of access to land and poor infrastructure. Poor roads and bridges make access to rural areas difficult, hence compromising the delivery of farm inputs (e.g., fertilisers and seeds), access to external learning platforms by farmers, as well as access to markets. This is aggravated by extreme poverty, poor health, and malnutrition of vulnerable groups, who are also often illiterate, making it difficult furthermore to build adaptive capacity at the local level. High prevalence of HIV/AIDS puts a major drain on family energy, cash, and food (Casale et al. 2010), undermining time and other resource investments (e.g., labour, cash) in food production and pursuance of other livelihood opportunities. This failure in other key sectors of rural development will put a strain on climate change adaptation.

5.3 Agricultural Policies for Climate Change Adaptation

5.3.1 State of Knowledge on Policies and Strategies for Climate Change Adaptation in the Agricultural Sector

In all the three focus countries in this study, the major policy and strategic considerations for climate change adaptation are variables contained or implicitly implied within and outside agricultural policy frameworks. However, there is a clear reflection that the major national policy documents are informed by the international and regional conventions and discourse on climate change, particularly those derived from UNFCCC, NEPAD, and SADC.

Climate Change Considerations in National Agriculture Sector Policies and Strategies

In Malawi, climate change adaptation is covered in several government agricultural policy and strategy documents including the Food Security Policy 2006, National Agricultural Policy (2010–2016), Agriculture Sector Wide Approach (ASWAp) of 2010, National Water Policy (revised 2005), National Disaster Risk Management Policy, National Land Resources Management Policy and Strategy and National Irrigation Policy, and Development Strategy of 2000 among others (Government of Malawi 2006, 2011). Out of these documents, the National Agricultural Policy, which is mirrored by the ASWAp, explicitly provides action points for climate change adaptation. The ASWAp is a response to Millennium Development Goal 1 and to CAADP Pillars 1 and 2 (Government of Malawi 2011). It broadly focuses on agricultural growth and poverty reduction, but specifically addresses food security and risk management and sustainable land and water management. It is thus consistent with the National Agricultural Policy, which provides for the specific actions in relation to climate change adaptation:

1. Improving vulnerability assessments to provide early warning on food security. The ASWAp goes on to highlight a need for insurance against weather.
2. Enhancing food security and developing community-based seed and food storage systems.
3. Improving crop production through the use of appropriate technologies. The ASWAp emphasises the use of improved crop varieties that are tolerant to drought, and developing/implementing strategies for drought preparedness.

4. Increasing resilience of food production systems to erratic rains by promoting the sustainable dimba production of maize and vegetables in dambos, wetlands, and along river valleys. In this regard, the ASWAp emphasises protection of catchment areas and fragile areas including wetlands and rivers, as well as increased use of irrigation and development of small dams for water harvesting.
5. Developing a framework to ensure that all agricultural projects and programmes undertaken in the sector have had environmental impact assessments as required by the Environmental Management Policy and Act and the related international instruments.
6. Mainstreaming gender and HIV/AIDS issues.
7. Strengthening the capacity of all stakeholders in issues of mainstreaming environmental management in the agricultural sector.

The National Water Policy focuses on water resources management and development and recognises the increasing incidence of droughts and floods. It calls for better catchment management to maintain/enhance ecosystems functioning and preserve biodiversity, including protection of wetlands. The National Irrigation Policy and Development Strategy focus on irrigation development to reduce dependence on rainfed agriculture. However, it does not recognise potential negative impacts of climate change variability in irrigation development. It explicitly calls for measures to reduce impacts of climate change to minimize economic and cultural disruptions and dislocations of the most vulnerable people. Other documents, such as the National Gender Policy of 2000 in Malawi, do not offer clear action points on adaptation, although the latter recognises women as one of the most vulnerable groups to climate change and variability.

South Africa provides some of the major contrasts in agricultural policies and strategies for climate change adaptation, most likely due to the relatively low contribution of agriculture in the country to national GDP and therefore a different focus on the major pathways to economic development. The key guiding policies and strategies for agriculture in South Africa are contained in the Integrated Growth and Development Plan 2012 (Government of South Africa 2012). The document responds to the country's macroeconomic Medium Term Strategic Framework by addressing three of the twelve targeted outcomes: to achieve decent employment through inclusive economic growth; to have vibrant, equitable, and sustainable rural communities contributing towards food security for all; and to protect and enhance the country's environmental assets and natural resources. The policy document recognises the critical challenges of climate change, and clearly embraces the need for substantial public and private investments in irrigation; support of crop varieties and animal breeds that are tolerant to heat, water, and low soil fertility stresses; and imperative to build roads and marketing infrastructure to improve small farmers' access to critical inputs as well as to output markets. The policy framework also dovetails well with the Comprehensive Rural Development Programme (CRDP) of the Department of Rural Development and Land Reform (DRDLR). The CRDP focuses on three main pillars, namely land reform, agrarian transformation, and rural development (Government of South Africa 2009). The CRDP addresses several critical developmental issues that focus on reducing vulnerabilities of the socially diverse rural communities, and is relevant to enhancing climate change adaptation processes including:

1. The empowerment of rural communities, especially women and the youth, through facilitating and mediating strong organisational and institutional capabilities and abilities to take full charge of their collective destiny.
2. Capacity-building initiatives, in which rural communities are trained in technical skills, combining them with indigenous knowledge to mitigate community vulnerability, especially with climate change, soil erosion, adverse weather conditions and natural disasters, hunger, and food insecurity.
3. The establishment of business initiatives, agroindustries, cooperatives, cultural initiatives, and vibrant local markets in rural settings.
4. Revitalisation and revamping of old, and the creation of new, economic, social, and information communication infrastructure and public amenities and facilities in villages and small rural towns.
5. Empowerment of rural communities to be self-reliant and able to take charge of their own resources.
6. Development of mitigation and adaptation strategies to reduce vulnerabilities with special reference to climate change, erosion, flooding, and other natural disasters.
7. Increased production and sustainable use of natural resources, including related value-chain development in crop farming (exploring all possible species, especially indigenous plants, for food and economic activity).

The above policy and strategy documents evidently build on the Integrated Food Security Strategy for South Africa (Government of South Africa 2002), which was launched with the overarching objective to eradicate hunger, malnutrition, and food insecurity by 2015. Some of the key specific objectives of the strategy were to:

(a) Increase household food production and trading.
(b) Improve income generation and job creation opportunities.
(c) Improve nutrition and food safety.
(d) Increase safety nets and food emergency management systems.
(e) Improve analysis and information management systems.
(f) Provide capacity building.

The strategy involved a wide range of interventions that included food production, infrastructure development, storage and transportation of food, social security grants, food emergencies, and microfinancing. However, lessons drawn from the initiatives and their contributions to climate change adaptation thus far have not been clearly reflected in the new policy documents.

In Zimbabwe, the agriculture sector policies and strategies are provided for in the Comprehensive Agriculture Policy Framework 2012–2032 (Government of Zimbabwe 2012), which supersedes the Zimbabwe Agricultural Policy Framework 1995–2020, which was rendered nonfunctional by the government's land reform programme of 2000. The new policy framework was necessitated by the need to address the country's new challenges and opportunities in the agricultural sector, in line with the national macroeconomic policy contained in the Zimbabwe Medium Term Plan 2011–2015. The major policy objectives as outlined in the document include:

- Assure national and household food and nutritional security.
- Ensure that the existing agricultural resource base is maintained and improved.
- Generate income and employment to feasible optimum levels.
- Increase agriculture's contribution to gross domestic product.
- Contribute to sustainable industrial development through home-grown agricultural raw materials.
- Expand significantly the sector's contribution to the national balance of payment.

Surprisingly, the policy framework is largely silent on climate change, and does not put any emphasis on specific challenges related to rainfall variability, increasing temperatures, and frequent droughts and occasional floods affecting the sector. This is despite the apparent recognition by the government of the high vulnerability of this national livelihood pillar to the pending negative impacts of climate change and variability. Climate change is only mentioned explicitly under crop diversification, with a specific focus on breeding of drought-tolerant crops, apparently offering a limited scope for adaptation. This implies that climate change adaptation is not considered a development issue within the agricultural sector. However, a National Policy and Programme for Drought Mitigation is also in place, which provides for provincial and district programmes to access funding from international organisations for purposes of drought mitigation. The policy framework has also guided the establishment of regional early warning systems and drought monitoring centers (Chagutah 2010). The country's National Water and National Irrigation Policies, along with a number of other policies, are also under development as the country recovers from more than a decade of sociopolitical and economic crisis. These emerging policies offer opportunities for addressing some of the deficiencies on climate change adaptation in the new agricultural sector policy document.

Climate Change Considerations in Regional Agriculture Sector Policies and Strategies

All countries in Southern Africa are members of the African Union and SADC. Malawi, South Africa, and Zimbabwe are therefore all signatories to major regional treaties and protocols that guide economic development to safeguard natural resources and the environment for the benefit of the region's diverse populations. One of the African Union's major development initiatives is NEPAD (AU/NEPAD 2003), and all the countries subscribe to its programmes. Particularly relevant to the regional agriculture sector is CAADP, which implicitly embraces climate change issues under its strategic Pillars 1 and 3. Pillar 1 of CAADP seeks to extend the area under sustainable land management and reliable water control systems. Pillar 3, on the other hand, aims to increase food supply and reduce hunger across the region by raising smallholder productivity and improving responses to food emergencies. Although the two pillars strategically address some of the fundamental sources of vulnerability to climate change and vulnerability by communities in Southern Africa, their design formulation was apparently not from a climate change adaptation perspective. CAADP is also consistent with the joint efforts of the European Union member states to fulfil the United Nations' Millennium Development Goals.

SADC has developed a Regional Agricultural Policy (RAP) (SADC 2012) which seeks to harmonise policy for agriculture and natural resources and strengthen the interventions so far guided by the SADC Regional Indicative Strategic Development Plan (RISDP) of 2003. One of the major areas of focus for the RAP is to reduce vulnerability in its broad sense. The policy document specifically identifies the regional agriculture sector as vulnerable to climate change and variability, and recognises the critical need for adaptation. The policy also draws on the momentum of earlier protocols on agriculture, although these are not explicit on how to address climate change adaptation challenges. These include:

- The SADC Dar-Es-Salaam Declaration on Agriculture and Food Security of 2004, which prioritised sustainable food security as well as environment and sustainable development.
- The SADC Maputo Declaration of 2003, which required countries to commit at least 10 % of their national budgets to agriculture.
- The Maseru Protocol of 1996 (eventually launched in 2008), which sought to establish a SADC Free Trade Area to enable member states to liberalise trade through the removal of tariffs and nontariff barriers. South Africa is one of the countries that have fully implemented this Trade Protocol, allowing 99 % of imports from within SADC to enter the South African market free of customs duties (Government of South Africa 2012).

These regional protocols and policy strategies offer opportunities to broaden the scope for climate change adaptation and draw on integration of major adaptation processes that may be warranted at the transborder and regional scales.

The Common Market for Eastern and Southern Africa (COMESA), to which Malawi and Zimbabwe, but not South Africa, are members, is a regional organisation with a principal focus on agricultural development as a means for achieving economic growth, industrial takeoff, agricultural trade, and employment creation. In 2002, the organisation passed a COMESA Agricultural Policy aimed at harmonising national policies of member states towards a COMESA Free Trade Area FTA. Subsequently, the COMESA Nairobi Declaration of 2004 on Expanding Opportunities for Agricultural Production, Enhanced Regional Food Security, Increased Regional Trade and Expanded Agro-Exports through Research, Value Addition and Trade Facilitation was a milestone in pursuance of regional integration. Positive outcomes of these policy initiatives include the Maize without Borders Policy Platform. The COMESA policy initiatives may offer a conducive policy environment for broad-based climate change adaptation and disaster risk reduction management interventions in the region.

Agriculture Considerations in Climate Change Policies and Strategies

The development of climate change policies and strategies of national governments in Southern Africa is essentially a work in progress, as both awareness and understanding of processes is still gathering momentum, courtesy of the UNFCCC processes. Malawi and South Africa have already completed development of their climate change response policies and strategies. The national strategy for Zimbabwe is under preparation. A National Climate Change Office has been established under the Ministry of Environment and Natural Resources. A national interministerial task force on climate change was also formed. Invariably across the three countries, the climate change policies and strategies are housed in the national ministries of the environment.

The Government of Malawi, through the Environmental Affairs Department of the Ministry of Environment and Climate Change Management, launched its National Climate Change Policy in 2012 (Government of Malawi 2012) with the objective to 'reduce vulnerabilities and promote community and ecosystem resilience to the impacts of climate change'. Climate change adaptation is ranked first out of eight key priority areas. The Malawi National Adaptation Programme of Action (NAPA) of 2006 (Government of Malawi 2006), which was developed as part of the UNFCCC process, is embraced by the new policy. All five prioritised adaptation options under the NAPA are strongly related to agriculture and aimed at increasing resilience of vulnerable communities to climate-related risks and disasters:

1. Improving community resilience to climate change through the development of sustainable rural livelihoods
2. Restoring forest in Upper, Middle, and Lower Shire Valleys catchments to reduce siltation and the associated water flow problems
3. Improving agricultural production under erratic rains and changing climatic conditions
4. Improving Malawi's preparedness to cope with droughts and floods
5. Improving climate monitoring to enhance Malawi's early warning capability and decision making and sustainable utilisation of Lake Malawi and lakeshore areas resources

However, lack of funding has been a major constraint to implementation of the Malawi NAPA, at least up to 2013. The National Disaster Risk Reduction Framework of 2010 provides for strengthening of early warning systems, addressing a critical area for development processes in agriculture.

In South Africa, the National Climate Change Response Strategy was developed in 2004, with the main objective to 'support the policies and principles laid out in the Government White Paper on Integrated Pollution and Waste Management, as well as other national policies including those relating to energy, agriculture and water' (Government of South Africa 2004). The strategy recognises the vulnerability of the agricultural sector, including rangelands, forests, and crops. The document also puts significant emphasis on mitigation. Unlike in Malawi, where adaptation in the agricultural sector is an obvious priority area, the sector is apparently not as emphasised in South Africa. This is most likely due to the relatively low contribution of agriculture to the national GDP.

5.3.2 Review of Key Arguments for Policies on Adaptation to Climate Change in the Agricultural Sector

The majority calls for supportive policies on climate change adaptation in the agricultural sector in Southern Africa arise from the increasing realisation of the threats to food security at household and national levels, supply of industrial raw materials, and national employment. This is particularly critical for countries such as Malawi and Zimbabwe, where the livelihoods for the majority of the national population are dependent on rainfed agricultural systems (e.g., Government of Malawi 2012; Government of Zimbabwe 2012). Consistent with CAADP and the strategic policy objectives of SADC and COMESA, agriculture is viewed as the main vehicle for economic growth in Malawi and Zimbabwe, where the national agricultural policy frameworks deliberately seek to enhance its contribution to GDP. Although South Africa's agriculture and forestry sector constitute a small proportion of the national GDP (around 3 %), the government still recognises its critical role in national and household-level food security; ensuring social and economic growth and development through job creation; and contributing to the rural socioeconomic development, particularly among the country's rural communities (Government of South Africa 2012). For example, about 70 % of total grain production in South Africa consists of maize, a climate-sensitive crop in the context of Southern Africa. Predictions of yield declines in excess of 20 % will therefore have a significant negative impact on the country's rural poor. There are also fears that any changes in rainfall and temperature may cause significant changes in areas uniquely suitable for specialised production of cash crops for export (Government of South Africa 2004).

5.3.3 Review of Key Policy Actors and Networks Involved with Adaptation to Climate Change in the Agricultural Sector

The majority of policy-related interventions on climate change adaptation in Southern Africa has been at a research level, out of which fewer than 50 % have focused on policy in a significant way. However, there has been significant involvement of development partners, NGOs, international research organisations, and regional policy networks in many of the research projects (Table 1), providing leverage for possible policy advocacy and dialogue processes. However, the total number of completed and ongoing projects for which there is published evidence is very small in relation to the magnitude of the problem. Most of the policy-related projects have also focused mainly on awareness raising (Table 8), most likely because of lack of empirical evidence at the local level.

5.3.4 Key Barriers to Uptake of Research Evidence for Policy Formulation

There is generally no documentation of evidence-based policy-making processes and their impacts in most of the countries in Southern Africa. Addressing these deficiencies is particularly important in the development of climate change adaptation policies, which have ramifications across different development sectors. Notable barriers to uptake of research evidence in Southern Africa include the following:

- Disconnect between UNFCCC processes and local-level evidence of the nature and causes of vulnerability of livelihood systems as well as mechanisms for adaptation.
- Lack of strategic incentives and appropriate institutional and policy mechanisms for involving different levels of policy makers in development research processes.
- Most of the literature revealed a lack of dialogue between research and development practitioners and policy makers as a major barrier. Interventions that broke this barrier, such as CCAA projects and the Government of Zimbabwe/UNDP/GEF Coping with Drought and Climate Change project, recorded positive outcomes.
- Limited research capacity to generate the necessary evidence: Most of the research studies are (for various reasons) isolated in time and space, requiring significant effort by researchers to consolidate (e.g., meta-analysis of existing data from different but related studies) and/or synthesise and discern key policy messages.
- Limited capacity of policy-making bodies to assimilate empirical research outputs. Those studies involving participatory action and colearning processes provide evidence that the capacity of policy makers at different levels can be enhanced, including their capacity to demand research results as opposed to the current dominance of supply-driven policy briefs and research findings sent to policy makers.

5.4 Gaps in Climate Change Adaptation Research and Policy in the Agricultural Sector

The study revealed several research and policy gaps that if addressed could enhance climate change adaptation processes at different levels in Southern Africa. Overall, the critical lack of empirical research and development studies/interventions covering diverse contexts already accounts for many of the glaring knowledge gaps.

Table 8 State of knowledge of stakeholder involvement on adaptation to climate change in the agricultural sector in Southern Africa

Country	Stakeholders	Category	Work done	References
Zimbabwe	Lutheran Development Services	Research/Policy	• Building adaptive capacity and sustainable livelihoods of smallholders in Makuwerere Ward, Mberengwa through gulley reclamation, conservation farming, and documentation of climate change initiatives and policy recommendations related to climate change	Brown et al. (2012)
Zimbabwe	SOFECSA	Research	• Learning centre concept (farmers self-mobilise and come up with technologies to adapt to climate change, e.g., staggering of crops, growing of small grains and different crop varieties) • *Zundera Mambo* concept (social safety net): chief supports communal production of staple maize and maintains a strategic grain reserve for the disadvantaged during years of crop failure	Mapfumo et al. (2013)

(continued)

Table 8 (continued)

Country	Stakeholders	Category	Work done	References
Zimbabwe	Department of Meteorological Services; FAO	Research	• Mid-term forecasting and provision of forecast information to smallholder farmers	Chikoore and Unganai (2001)
Zimbabwe	Government of Zimbabwe; United National Environment Programme (UNEP); UNDP; GEF	Research	• Assessed vulnerability of smallholder farmers in Chiredzi District and developed adaptation strategies • Addressed vulnerability drivers; climate risk management through enhancing use of early warning systems and developing community drought preparedness plans	Brown et al. (2012)
Zimbabwe	Practical Action	Research/Policy	• Mainstreaming livelihoods approaches to disaster risk reduction so as to ensure policy makers at district, provincial, and national level adopt a livelihood-centered approach to disaster risk reduction	Brown et al. (2012)

Country	Stakeholders	Category	Work done	References
South Africa	Rawsonville Cooperative; Oxfam Partner Organisation	Research	• Helped seasonal and unemployed workers increase their income through growing gourmet mushrooms and planting crops that survive in cold weather	Vincent et al. (2011)
Malawi	Alliance for a Green Revolution in Africa (AGRA)	Research/Policy	• Supporting agriculture development across the chain, from funding projects on seeds and soils to markets and policies	www.agra-alliance.org
Malawi, South Africa, Zimbabwe	African Agricultural Technology Foundation (AATF); ASARECA	Research	• Crop development and technology transfer for African farming systems through crop breeding	www.aatf-africa.org, www.asareca.org

(continued)

Table 8 (continued)

Country	Stakeholders	Category	Work done	References
Malawi, South Africa, Zimbabwe	Action Aid International; ACT; Africare; African Technology Policy System (ATPS); Bureau for Food and Agricultural Policy (BFAP); CGIAR; FAO; Forum for Agricultural Research in Africa (FARA); World Agroforestry Centre (ICRAF)	Research/Policy	• Integration of disaster reduction into schools • Integration of vulnerability and adaptation to climate change into sustainable development policy planning and implementation • Training programmes on climate change adaptation for policy makers • Natural resources management including water harvesting techniques • Modeling of climate change effects on crops, especially maize, and access to technology • Information dissemination through radio plays • Conservation agriculture	Mumba and Harding (2009), www.africare.org, www.bfap.co.za, www.cgiar.org, www.fara-africa.org

Country	Stakeholders	Category	Work done	References
Zimbabwe	National Agricultural Extension Services (AREX)	Research	• Facilitates smallholder farmers to adapt and cope better with climate variability and change through use of NGOs' global experiences on climate change adaptation and research in agriculture and meteorological services in developing countries	Mapfumo et al. (2013)
Mostly Africa	Environnement et Développement du Tiers-Monde (ENDA)	Policy	• Lobbying, policy dialogue, and multilateral agreements on climate change • Community-level climate change adaptation programmes, multiscalar activities	www.enda.sn

(continued)

Table 8 (continued)

Country	Stakeholders	Category	Work done	References
Malawi, South Africa, Zimbabwe	National universities including the University of Zimbabwe, University of Free State and Bunda College of the University of Malawi	Research	• Researchers and students conduct work on climate change adaptation and colearn with smallholder farmers to be innovative and use 'best-fit' techniques in their fields • Education and training workshops: a programme of policy research and teaching fellowships with related curriculum • Development and strategic matching of African and international institutions, where outside knowledge and resources can enhance given areas of expertise • Researchers are working with planners and farmers to develop modeling scenarios that will improve access to climate information and offer a range of options to help them prepare for a water-scarce future • Climate change adaptation for improved livelihoods in Malawi	Denton et al. (2010), Synnevag and Lambrou (2012)

Country	Stakeholders	Category	Work done	References
Malawi	Ministry of Agriculture and Food Security	Research	• Dissemination of climate-smart agricultural technologies such as reduced tillage, agroforestry trees, legumes and improved maize varieties through the research and extension system	Synnevag and Lambrou (2012)
South Africa	IDRC in collaboration with researchers from the University of Cape Town, University of Kwa-Zulu Natal, and University of Free State	Policy	• Development of a model that will allow policy makers to make informed adaptation decisions based on a combination of regional climate change models that can measure impact on water levels, farming systems, and urban water use • Enable capacity building among water managers, academic community, and general public with regard to climate change variability, vulnerability, and possible adaptation strategies	www.idrc.ca/ccaa
South Africa, Malawi, Zimbabwe	FANRPAN	Research/Policy	• Food security and the impacts of CC. Also some work on vulnerability • Research into adaptation strategies and building research capacity	www.fanrpan.org

(continued)

Table 8 (continued)

Country	Stakeholders	Category	Work done	References
Malawi	Red Cross	Research	• Disaster relief and climate change adaptation	www.redcross.org
South Africa	SouthSouthNorth	Research	• Community-based capacity building, e.g., drought-resistant Rooibos tea varieties	www.southsouthnorth.org
Africa	World Wide Fund for Nature (WWF)	Research	• Nature conservation, natural resource management	www.worldwildlife.org
Zimbabwe	Zimbabwe Regional Environment Organisation	Research/Policy	• Capacity building through installation of wind power for home use and irrigation pumps, helping rural villages to cope with water shortages • Scaling up local adaptation needs to national and international policy	www.zeroregional.com

- *Building empirical evidence of climate change impacts and application of adaptation options*: The current body of knowledge within the region is too thin to inform the formulation of comprehensive climate change policy frameworks and implementation plans. The intricate nature of economic, governance/political, technical, and sociocultural factors determining vulnerability and adaptive capacities of households, communities, and institutions make climate change adaptation one of the most complex subjects of development research in the region. Implications for capacity building in terms of methodologies, approaches, technical expertise, and research infrastructure are therefore bigger than can currently be served by tradition.
- *Harmonisation of concepts, methods, and tools for vulnerability assessment*: A number of vulnerability assessment studies have been conducted, but it remains unclear if different methods are necessary for understanding climate change. The concept of vulnerability in the context of climate change is clearly defined in IPCC reports, but conclusions have been made in some climate change literature based on somewhat different concepts. This has implications for how policy-making processes are subsequently influenced.
- *Identifying critical variables for improving quality of seasonal forecasts and early warning systems*: Most of the national policy and strategy documents emphasise the importance of seasonal weather forecasting and early warning systems, but there is no clarity on critical variables to be monitored, and the requirements for matching instrumentation and associated expertise at the national and regional levels to improve the quality of data on forecasts.
- *Lack of data and empirical studies to inform budgetary processes for adaptation*: There was limited evidence on quantification of the costs of adaptation processes for specific communities. Operationalisation of adaptation action plans is therefore in itself a major challenge, and is likely by be constrained by poor justification of both actions and budgets.
- *Understanding microlevel impacts of climate change and variability in agricultural systems*: Climate change and variability impacts on agriculture have tended to be reasoned on the basis of traditionally known factors regulating biophysical (physical, chemical, and biological) and socioecological (interactions) processes. However, one of the impacts of climate change may be an alteration of these regular processes (e.g., soil processes, biodiversity, hydrological cycles, human systems behaviour). Specialist process research is therefore necessary to understand microlevel impacts of climate change and variability in agricultural production systems. Examples in agriculture include revisiting the current understanding of:

  – Dimensions of crop–soil–water interaction patterns to enhance efficiency of resource use and targeting. For example, increasing efficiencies in the use of available nutrient and water resources in crop production systems is likely to be a major determinant of adaptation options in Southern Africa where production is constrained by a combination of poor fertility soils and water scarcity.

  - Emerging patterns and causes of postharvest losses in crop production systems.
  - Emerging patterns in agrobiodiversity such as climate change and variability impacts on pollinators, soil processes, crop–pest and crop–disease interactions.
  - Options for designing efficient management systems for forestry to reduce overexploitation and postharvest losses.

- *Role of traditional institutions in fostering and maintaining resilience*: Families and communities in Southern Africa have also survived in marginal environments because of strong institutions supporting extended family lifestyles and vibrant rural–urban interconnections. Development policies in the region have been exceptionally silent in recognising the contribution of these institutional arrangements on the resilience of livelihood systems at local, national, and regional (transborder) scales. The dynamics of these social collaborations (and conflicts) in response to climate change and variability effects (direct or indirect) have not received due attention, yet they underpin cross-generational survival strategies for the majority of people in the region. This is despite clear evidence that effective climate change adaptation options are likely to be those rooted in indigenous knowledge systems and built through the local practices. Comprehensive research on these issues is likely to generate key development insights that can inform cross-cutting policies, especially those related to gender and HIV/AIDs. Currently there is a strong show of will on gender mainstreaming in agriculture and natural resources management, but the content on the mechanisms is critically lacking.
- *Critical analysis of resource use efficiencies and tradeoffs for current and alternative adaptation options*: Institutional mechanisms regulating interactions among cropping and natural resources (including wildlife and forestry) management schemes within rural communities and between rural and urban/peri-urban communities need to be evaluated. This indicated that climate change can influence resource access and sharing arrangements, and sociopolitical conflicts related to resource governance, as well as the relative impacts of technological interventions/access. Further understanding is required on how climate change and variability may enhance or upset some of the key traditional sources of resilience for diverse farming communities.
- *Understanding emerging gender dynamics in the context of climate change adaptation*: Evidence is only beginning to emerge which suggests changing gender roles in response to impacts of climate change and variability, and interventions that yield a critical analysis on the direction and magnitude of such changes as well as effects on livelihood systems is required. This may help to inform the discourse on gender and climate change in agriculture. Current policies indicate increasing awareness of gender issues among stakeholders, but there is no clear evidence of contents. Studies are lacking on how the evolution of what are depicted as local cultures and social values today within the predominantly vulnerable communities have been shaped by environmental marginality and past

sociopolitical systems. Such studies could provide key insights on the current value systems as an outcome of past adaptation processes, or lack thereof.

- *Development of options for commercialisation of smallholder agriculture*: There is a need for expanded research programmes with options for sustainable agricultural intensification, and on understanding circumstances where extensification may hold promise now and in the future. Outcome of analyses of tradeoffs between extensification and intensification options is likely to be critical in informing future policy directions. Currently, there is also a glaring knowledge gap and no data on climate change and variability effects on production and trade of industrial export crops that include cotton, rice, coffee, cashew and macadamia nuts, tobacco, groundnut, tea, sugarcane, and horticultural crops (especially flowers).
- *Development of 'climate-smart agriculture' systems*: This is an area that has gained momentum in research over the past few years, but the conceptualisation and application of the underlying principles has generally been informed by speculative arguments with no supporting empirical evidence. This is likely to misdirect policy-making processes on the potentials and limitations of emerging agricultural technologies and their suitability to diverse local contexts. For example, a wide range of ISFM and CA technologies have been developed and tested under different agroecologies in the region, but their potential role in climate change adaptation has largely not been studied in sufficient detail to inform policy.
- *South African agriculture in transition*: Improvement of agriculture's contribution to national GDP is not a major objective of South African agricultural policy at present, and this has implications for the dynamics of vulnerabilities and therefore on relative adaptive capacity of the country's rural communities to climate change. Currently, 95 % of the country's marketable crop is produced in the large-scale commercial sector. Perceptions about the declining importance of farming in South Africa may possibly send an 'out of fashion' message to the country's youth, with strong implications for the future of national and regional food security as well as the economics of industrial development.
- *Analysing tradeoffs between irrigated and rainfed systems*: Although irrigation development is emerging as a major area of focus for national policies and strategies, the potential negative impacts of declining rainfall patterns on agricultural water have tended to be ignored in policy formulation. There are no clear indications that due consideration is being given to options for increasing productivity in rainfed cropping systems. With no empirical evidence to back up some of the policies supporting big investments in irrigation infrastructure development, costly miscalculations could be made.
- *Critical analysis of implications of past research and development intervention programmes on current and possible future manifestations of vulnerabilities*: Current discourse seems to imply that existing livelihood systems inherently lack resilience regardless of the differences in community exposures to multiple stress factors other than climate change and variability. However, there is little empirical evidence demonstrating how, and to what extent, past intervention pro-

grammes have really reduced vulnerabilities of the poor and disadvantaged rural communities. The changing context of development interventions due to climate change may also require governments to revisit some of the past development policies that may be now rendered relevant. Climate change also brings to the fore possible weaknesses in current approaches and methodologies for measuring vulnerability and impact in development (e.g., against the changing context of development interventions and multiple stress factors).

- *Generation of context-specific adaptation options*: There is limited empirical data upon which generalisations of potential impacts of climate change in a country can be made to inform local adaptation processes, yet adaptation is well known to be a local phenomenon. This strongly suggests a need to generate site-specific data and empirical evidence that can inform technical interventions and policy processes at the local level. This also brings to the fore the importance of engaging local-level decision makers as probably more important agents of change than national and regional stakeholders.

6 Conclusions

The concluding remarks outlined below are with respect to the key questions.

1. *What is the role of climate change challenges in the context of the multiple challenges and opportunities facing the agriculture sector in the African region?*

   The African continent is particularly vulnerable to the impacts of climate change affecting key economic drivers such as water resources, agriculture, and disaster risk management, among others. The impacts include water stress and scarcity; food insecurity; and high costs of disaster management as a result of increased frequency and intensity of droughts, floods, and landslides associated with the El Niño phenomenon.
2. *What is the current state of knowledge on adaptation to climate change in the agricultural sector in the African region?*

   There is a considerable amount of research on climate change adaptation in the agricultural sector in Africa. From the analysis of adaptation work, agricultural research appears to be a crucial area of adaptation to climate change in order to deal with changes in the length of growing seasons, increased droughts, and periodic waterlogging as well as increased temperature and salinity in the area. National Agricultural Research Centers and the private sector in areas expecting more droughts in the future should be supported to enable agricultural adaptation, taking on board climate-smart agricultural practices. CA is best suited for smallholder farmers in the region.
3. *What is the current state of knowledge on whether and how research findings are integrated in agriculture sector policies in the African region?*

   Despite a considerable number of climate change adaptation research projects in the African region, there is little evidence regarding how the generated knowledge is made useful or integrated in the agricultural development plans of the respective countries. The link between agricultural research in the context of climate change and policy-making processes needs to be strengthened. This implies that the various agricultural policies and initiatives within the African region are based on the knowledge generated to enhance adaptation. This can be achieved through proper packaging of research findings in a user-friendly way and sharing those findings through research-policy dialogues.

4. *What are the major gaps in research on adaptation to climate change in the agricultural sector?*

   Analysis of knowledge generated from adaptation research on the agricultural sector shows that little has been done to ensure that climate-resilient approaches are integrated into the sector. This includes the use of climate-smart agriculture. More research is also needed to show the interlinkages of the agricultural sector and other related sectors such as water and energy. Integrated approaches are needed in development interventions aimed at promoting adaptation to climate change. Smallholders are exposed to global environmental change and economic globalisation, leading to competition between smallholder produce and highly subsidised produce from industrialised countries. Combining local and scientific knowledge systems is important for making climate information relevant locally and for empowering communities, and is further necessary to enhance adaptation in the agricultural sector.

5. *What is needed to ensure that research findings are better integrated into agriculture sector policies?*

There is a need to ensure that findings from agricultural research for climate change adaptation are well packaged and made user-friendly to various categories of stakeholders. There is also need for a mechanism to link stakeholders at the grassroots and other levels, vertically and horizontally. The aim is to develop a regional climate change policy and strategies to respond urgently to the adverse impact of climate change that includes addressing the challenge of food insecurity as a result of the extreme climatic conditions associated with climate change.

7 Recommendations

7.1 Tackling Climate Change in the Context of Multisector Challenges

A comprehensive approach involving coordination of activities in the crops and forestry sectors is recommended, taking cognisance of the cross-cutting issues of water, energy, and gender. Interdisciplinary research, as appropriate, is therefore required. Fundamental to success in adaptation is good governance in the form of rule of law, decentralisation, and participation of citizens in decision making that creates the environment for social cohesion, rapid agricultural growth rates, and GDP growth that translate into improved human development.

7.2 Improving Adaptation to Climate Change by Smallholders

Improved access by smallholders to best bets, through diagnosis of problems and on-farm demonstrations/adaptive trials and improved dissemination systems, improved credit systems by way of strengthening rural banks and microcredit schemes, and improved access to markets through better infrastructure (storage, feeder, and major road networks) are required. Training on the options for adaptation to climate change is required. For sustainability, local communities should have ownership of interventions in adaptation.

7.3 Filling Gaps in Research on Adaptation to Climate Change

Both conventional scientific research and participatory action research should be employed as appropriate as they complement each other. Conventional research is more proactive and can therefore forestall disasters. The right balance between research for developing short-term and long-term strategies should be kept. There is a need for research at various levels on both the mitigation and adaptation aspects of climate-smart agriculture, their interactions and tradeoffs. The complementary roles of indigenous knowledge and scientific knowledge should be recognised at all levels of adaptation.

7.3.1 Technical Research on Crops

The tentative research themes and topics include: crop improvement for yield and tolerance to biotic and abiotic stresses; effects of climate change on incidence of crop pests and diseases; fine tuning conservation agriculture to diverse biophysical and socioeconomic conditions for improved smallholder uptake; increasing quality and adding value to crops products; nutritional value of processed products; improving efficiency of agricultural water use in the crops sector; reclamation of land degraded by salty water; prolonging the growing season; climate change and tree crops; screening and matching agroforestry species and plant populations with ecological zones and agricultural practices; and agroforestry and use of biochar as technologies for soil improvement and climate-smart agriculture.

7.3.2 Socioeconomics and Policy Research

Research is recommended on the policy process and political factors influencing priorities and affecting adaptation; land use patterns and adaptation; land use regulations; costs and returns of adaptation options, quantity, and value; ex ante evaluation of adaptation options, effectiveness of adaptation options, adoption rates and determinants of adoption; analysis of existing marketing structures to improve efficiency and determine how regional integration of markets and access to global markets will be important in responding to climate change; gender considerations in adaptation to climate change and variability; and effect of knowledge of climate change and variability on achievement of national development goals including poverty reduction and food security at national and regional levels. Improved modelling capability would facilitate technical and socioeconomic research.

7.3.3 Risk Management Dealing with Stocks, Weather Forecasting, and Insurance

Risk management should involve feasibility studies of buffer stocks (grain reserves), improvement in the quality of meteorological data collection and weather forecasting tools and techniques, and therefore early warning systems to reflect the needs of farmers; and innovative insurance schemes for smallholder crop farmers. The latter should include rainfall indices for crops.

7.4 Improving Policy Formulation and How Research Findings Can Be Better Integrated into Agricultural Policies

National policies on agricultural development and climate change adaptation should be evidence based and provide an enabling environment for maintaining or improving the productivity of land, water, and labour under a changing climate. This will involve policies to facilitate access by smallholders to credit and markets, policies to improve institutional capacity and infrastructure, smart subsidies, insurance schemes for smallholders in crops, and crisis management. Sustainable food security must be made the central concern. Farmers should be provided with financial incentives to adopt climate-smart agricultural practices. The linear 'research to policy model' should give way to more participatory approaches. To be useful in supporting policy formulation, strategies for adapting food systems to climate change and variability must be elaborated in the context of the policy processes. Better still, policymakers must be brought into the research loop very early.

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