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The influence of current and future climate-induced risk on the agricultural sector in East and Central Africa

Sensitizing the ASARECA strategic plan to climate change

van de Steeg JA, Herrero M, Kinyangi J, Thornton PK,
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Acronyms

APSIM	Agricultural Productions Systems Simulator
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CIAT	International Center for Tropical Agriculture
DRC	Democratic Republic of Congo
ECA	Eastern and Central Africa
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO statistical database
GCM	General circulation models
GDP	Gross domestic product
GHG	Greenhouse gas
GIS	Geographic information system
GLC	Global land cover
GRUMP	Global Rural-Urban Mapping Project
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
LDCs	Least Developed Countries
LGP	Length of Growing Period
MA	Millennium Ecosystem Assessment
NAPA	National Adaptation Programme of Action
NARS	National agricultural research system
PRECIS	Providing REgional Climates for Impacts Studies
R&D	Research and Development
RCM	Regional Climate Model
SRES	Special Report Emissions Scenarios
START	SysTem for Analysis, Research and Training
UNFCCC	United Nations Framework Convention on Climate Change
VOP	Value of Production
WMO	World Meteorological Organization

Executive summary

Rainfed agriculture is and will remain the dominant source of staple food production for the majority of the rural poor in Eastern and Central Africa (ECA). It is clear that larger investments in agriculture by a broad range of stakeholders will be required if this sector is to meet the food security requirements of tomorrow's Africa. Many factors contribute to the current low levels of investment, but production uncertainty associated with between- and within-season rainfall variability remains a fundamental constraint to many investors who often overestimate the impact of climate induced uncertainty.

The climate of Africa is warmer than it was 100 years ago. Model-based predictions of future greenhouse gas-induced climate change for the continent clearly suggest that this warming will continue and, in most scenarios, accelerate. The projections for rainfall are less uniform; large regional differences exist in rainfall variability. However, there is likely to be an increase in annual mean precipitation in East Africa.

For agricultural communities and agricultural stakeholders in ECA to adjust to climate change and the projected increases in temperature and in rainfall variability, their ability to cope better with the constraints and opportunities of the current climate must first be improved. Through this literature review, information will be made available on the current state of knowledge on the implications of current climate variability and future climate change on the agricultural sector within ECA.

We also assess the impact of climate change on agro-ecological characteristics by looking at changes in the length of growing period (LGP). Changes in rainfall patterns, in addition to shifts in thermal regimes, influence local seasonal and annual water balances, and in turn affect the distribution of periods during which temperature and moisture conditions permit agricultural crop production. Such characteristics are well reflected by LGP since most countries in ECA rely on rainfed agriculture.

In order to identify areas where current and projected impacts of climate change are likely to be significant, spatial explicit data layers with percentage changes in LGP to the years 2030 and 2050 for different models (the ECHam4 and the HadCM3 GCM) and development scenarios (A1F1 and B1) are combined. This was done using geographic information systems (GIS). This requires information on: (a) the spatial distribution of the extent of climate change and the impact of climate change on agro-ecological characteristics; (b) the prevailing agricultural production systems, their spatial distribution and how they are likely to evolve; (c) the prevailing crops and their spatial distribution; (d) the numbers of cattle, sheep and goats in each production system and their changes; and (e) the human population numbers in each production system and their changes.

The literature review and the spatial analysis to assess the impact of climate change yielded to the insights are discussed below.

1) The production uncertainty in the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) region associated with between- and within-season rainfall variability is a constraint to farming. In systems reliant on rainfall as the sole source of moisture for crop or pasture growth, seasonal rainfall variability is inevitably mirrored in both highly variable production levels and in the risk-averse livelihood and coping strategies that have emerged over time amongst rural populations. This is particularly evident in the semi-arid regions of ASARECA where current climate variability (i.e. rainfall) and climate extremes have their most profound impacts on production.

   Whilst seasonal rainfall totals and their season-to-season variability are in themselves important, the nature of 'within season' variability can also have a major effect on crop productivity. For example, there is a general trend of increasing yields as seasonal rainfall totals increases. But there is also considerable yield variation within the relationship resulting from the contrasting patterns of within-season rainfall distribution experienced in any given season.

2) The livestock based systems will be especially affected by changes in LGP, as these systems are predominant in marginal areas. Losses of more than 20% in LGP are expected in Eritrea, Ethiopia, Kenya and Sudan. However, some of the large losses are located in areas with LGP of less than 60 days, i.e. in highly marginal areas for cropping but important for pastoralists. Therefore a projected change of more than 20% in these areas could be the result of a change of 1 or 2 days in LGP that would not really influence the agricultural potential of these marginal lands.

3) ECA will have significant land use changes due to climate change and other drivers such as population density. These changes will be large in high potential areas. The areas under semi-arid and humid mixed rainfed farming systems will increase at the expense of temperate mixed rainfed and livestock based farming systems. For Ethiopia, for example, the temperate mixed rainfed systems will reduce from 26.6 million ha to about 13.9 million ha, while the semi-arid and humid rainfed systems will increase from respectively 18.1 and 2.0 million ha to 28.3 and 7.4 million ha. These areas will be of paramount importance to adapt to changes in climate to be able to feed large numbers of (poor) people.

4) A large variety of commodities are produced in ECA, their spatial distribution depending on food preference and on biophysical and socio-economic factors. The importance of these different agricultural commodities varies by country and by production system. The value of agricultural production, a product of annual production and average annual price of a commodity, was used to assess the relative economic importance of commodities in the region. In economic terms cassava, maize, sweet potatoes and sorghum are the most important crops, closely followed by rice, banana/plantain, potatoes and beans. These crops are also the main staple crops for the different countries.

5) Each agricultural commodity is affected differently by variability in current climate characteristics and will be affected differently by climate change. The distribution of crop commodities is highly variable. The cultivation of many crops is currently in areas that are projected to undergo moderate to severe losses in LGP by 2050. For example, cassava in Ethiopia, Madagascar and Sudan is grown in areas that are projected to have large losses. In Burundi, Kenya, Rwanda, Tanzania and Uganda cassava is grown in areas that are projected to experience moderate losses in 2050. For maize, moderate to large losses in LGP are projected in Eritrea and Madagascar; the losses are moderate in all other countries. Sweet potatoes are grown in areas that are projected to have moderate to large losses in LGP in the Democratic Republic of Congo (DRC), Madagascar and Sudan, and moderate losses in Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda.

6) Research and development efforts have tended to concentrate on adaptation options to climate change in marginal areas. However, significant adaptation will be required in highly populated and intensive high potential areas. As the major economic commodities are projected to be affected by climate change, the economic performance of the agricultural sector will be influenced. To be able to adapt to these changes there will be a demand for alternative crop varieties and crop substitution, and for a change in livestock feeding practices.

Glossary

Adaptation	Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.[i]
Adaptive capacity	The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences.
Adaptation strategies	All initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.[2]
Climate	The long-term average weather of a region including typical weather patterns, the frequency and intensity of storms, cold spells, and heat waves. Climate is usually defined as the 'average weather' or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years as defined by the World Meteorological Organization (WMO). These relevant quantities are most often surface variables such as temperature, precipitation and wind. [iii,1]
Climate change	Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.[1]
Climate variability	Variations in the mean state and other statistics (e.g. standard deviations or the occurrence of extreme events) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system or to variations in natural or anthropogenic external forcing.[1]
Coping	The use of existing resources to achieve various desired goals during and immediately after unusually abnormal and adverse conditions of an event or process. The strengthening of coping capacities, together with preventative measures, is an important aspect of adaptation and usually builds resilience to withstand the effects of natural and other hazards.[iv]

Drought	The phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.[1]
Emissions	The release of a substance (usually a gas when referring to the subject of climate change, e.g. the release of carbon dioxide during fuel combustion) into the atmosphere. Emissions can be either intended or unintended releases.[3,v]
ENSO	El Niño Southern Oscillation: El Niño is a warm water current that periodically flows along the coast of Ecuador and Peru. This event is associated with a fluctuation of the inter-tropical surface pressure patterns and circulation in the Indian and Pacific Oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is known as the El Niño Southern Oscillation or ENSO. During an El Niño event, the prevailing trade winds weaken and the equatorial counter current strengthens, causing warm surface waters in the Indonesian area to flow eastward and overlie the cold waters of the Peru Current. This event has a great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña.[1]
Evapotranspiration	The process by which water re-enters the atmosphere through evaporation from the ground and transpiration by plants.[vi]
GCM	General circulation model: A computer model of the basic dynamics and physics of the components of the global climate system (including the atmosphere and oceans) and their interactions which can be used to simulate climate variability and change.[6]
Global warming	Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, induced by both natural and human activities. In common usage, global warming often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities.[3]
Greenhouse gases	Those gases in the atmosphere which absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. Water vapour, carbon dioxide, nitrous oxide, methane and ozone are the primary greenhouse gases (GHGs) in the atmosphere.[1]
Impacts	The Consequences of climate change on natural systems and human health. Depending on the consideration of adaptation, we can distinguish between potential impacts and residual impacts. Potential impacts are all impacts that may occur given a projected change in climate, with no consideration of adaptation. While residual impacts are the impacts of climate change that can occur after adaptation.[1]
IPCC	The Intergovernmental Panel on Climate Change was established in 1988 by the WMO and the United Nations Environment Programme (UNEP). The IPCC is responsible for providing the scientific and technical foundation for UNFCC, primarily through the publication of periodic assessment reports.[3]

Mitigation	An anthropogenic intervention to reduce the sources or enhance the sinks of GHGs.[1,7]
National Adaptation Plans of Action	NAPA: Plans submitted to the Conference of the Parties (COP) by all Parties outlining the steps that they have adopted to limit their anthropogenic GHG emissions. Countries must submit these plans as a condition for participating in UNFCCC and, subsequently, must regularly communicate their progress to the COP.[2]
Projection	A potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from "predictions" in order to emphasize that projections involve assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized; they are therefore subject to substantial uncertainty.[1]
Resilience	The level of disturbance that an ecosystem can undergo without crossing a threshold to a situation with different structure or outputs. Resilience depends on ecological dynamics and the organizational and institutional capacity to understand, manage and respond to these dynamics.[vii]
Risk management	Risk management is activity directed towards assessing, mitigating (to an acceptable level) and monitoring risks. In some cases the acceptable risk may be near zero. Risks can come from accidents, natural causes and disasters, and from deliberate attacks from an adversary.
Scenarios	A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships. Scenarios are neither predictions nor forecasts and may sometimes be based on a narrative storyline.[1]
Sensitivity	The degree to which a system is affected by climate-related changes, either adversely or beneficially. The effect may be direct (e.g. a change in crop yield in response to temperature change) or indirect (e.g. damages caused by increases in the frequency of coastal flooding).[1]
Uncertainty	An expression of the degree to which a value (e.g. the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g. reflecting the judgment of a team of experts).[1,2,7]
UNFCCC	UN Framework Convention on Climate Change: Convention signed at United Nations Conference on Environment and Development in 1992. Governments that become Parties to the Convention agree to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.[1,2]

Vulnerability	The degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.[2]
Weather	Describes the short-term (i.e. hourly and daily) state of the atmosphere at any given time or place. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day, and season-to-season. Weather is not the same as climate.[3,7]

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[i] IPCC Third Assessment Report Working Group III: Mitigation.

[ii] IPCC Third Assessment Report Working Group II: Impacts, Adaptation and Vulnerability.

[iii] Glossary of US Environmental Protection Agency, EPA: http://www.epa.gov/climatechange/glossary.

[iv] Agrawal, A. 2008. The Role of Local Institutions in Adaptation to Climate Change. Washington, D.C.: The World Bank.

[v] Glossary of UNFCCC, http://unfccc.int/resource/cd_roms/na1/ghg_inventories/english/8_glossary/Glossary.htm#E.

[vi] Glossary of PEW Centre on Global Climate Change, http://www.pewclimate.org/global-warming-basics/full_glossary.

[vii] Millennium Ecosystem Assessment Ecosystem and Human well-being: Policy responses.

1. Introduction

The global mean surface temperature has increased in a linear trend of 0.74°C over the last 100 years (IPCC, 2007a). The warming is widespread, with a maximum at higher northern latitudes. Consistent with warming, mountain glaciers and snow cover have declined in both hemispheres. The global average sea level has risen since 1961 at an average rate of 1.8 mm per year and since 1993 at 3.1 mm per year, with contributions from thermal expansion and melting glaciers and ice caps, and the Greenland and Antarctic ice sheets.

A significant increase in precipitation has been observed in the eastern parts of North and South America, northern Europe and northern and central Asia. The frequency of heavy precipitation events has increased over most land areas. This is consistent with warming and increases in atmospheric water vapour. At the same time, there has been some drying in the Sahel, the Mediterranean, southern Africa and parts of southern Asia (IPCC, 2007a).

Widespread changes in extreme events have been observed. For example, cold days, cold nights and frost are less frequent, while hot days, hot nights, and heat waves are more frequent. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and sub-tropics. There is also evidence of increased intensity of tropical cyclone activity in the North Atlantic since about 1970 (Thornton et al., 2008).

The challenges climate change poses for development are considerable (Thornton et al., 2006). Although there are uncertainties about the future climate, it is necessary to explore how sensitive environmental and social systems and economically valuable assets are to climate change (Hulme et al., 2001). High levels of vulnerability and low adaptive capacity in areas of Africa have been linked to factors such as limited ability to adapt financially and institutionally, low per capita gross domestic product (GDP) and high poverty rates, and a lack of safety nets. For example, sub-Saharan Africa is predicted to be particularly hard hit by global warming because it already experiences high temperatures and low (and highly variable) precipitation, the economies are highly dependent on agriculture, and adoption of modern technology is low (Kurukulasuriya et al., 2006).

ASARECA

The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) was created in 1994. It is a non-political association of directors of research institutes in 10 countries in Eastern and Central Africa (ECA): Burundi, Democratic Republic of Congo (DRC), Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania and Uganda. ASARECA serves as a forum for promoting agricultural research and strengthening relations between national agricultural research systems (NARS) and the international agricultural research system. Its informal status as an association has provided it with flexibility in adapting to changing circumstances and opportunities (ASARECA, 2005).

The 10 ASARECA countries cover an area of 8.5 million km2 with a total population of more than 280 million people, most of whom are rural dwellers pursuing agricultural livelihoods (Table 1). The 10 countries have different social, political and economic histories, and thus also distinct legal and institutional structures and processes. Despite such differences, however, there is considerable similarity across countries in factors viewed to constrain agricultural development, and thus also in agricultural policy objectives (Omamo et al., 2006).

Table 1. Total land area and total cropland, total population and share of rural population, and GDP per capita for countries in ECA

Country	Total land area (× 1000 ha)	Total cropland (× 1000 ha)	Population (× 1000 count)	Share of rural population (%)	GDP per capita (PPP*)
Burundi	2,568	1,325	6,282	91.0	107
DRC	226,705	7,827	48,650	69.7	86
Eritrea	10,100	502	3,714	81.3	186
Ethiopia	100,000	10,950	65,597	85.1	121
Kenya	56,914	5,090	30,535	64.1	411
Madagascar	58,154	3,517	15,973	74.0	241
Rwanda	2,467	1,175	7,666	86.3	224
Sudan	237,600	16,675	31,443	63.9	369
Tanzania	88,359	4,950	34,832	67.7	269
Uganda	19,710	7,157	23,500	88.0	239

*PPP: Purchasing power parity.
(FAOSTAT, accessed in October, 2009)

Objective of the report

In recent years, reducing vulnerability to climate change has become an urgent issue. It is at the forefront of any sustainable development policy agenda. Adaptation to climate change is a process whereby individuals and communities seek to respond to actual or expected climatic stimuli or their effects. This process is not new. Throughout history, people have reported to have always responded to season-to-season variability in rainfall. What is new is the incorporation of climate change and its potential impacts into policy making and planning at a range of scales.

National Adaptation Plans of Action (NAPA) have been developed recently under the United Nations Framework Convention on Climate Change (UNFCCC) for least developed countries (LDCs). However, to date there is lack of a consolidated or coordinated approach to adaptation to projected climate impacts on a local scale. With the mandate to promote agricultural research in the region and with the flexibility to adapt to changing circumstances and opportunities, ASARECA is well suited to strengthen the regional capacity to deal with the influence of current variability in climate (i.e. rainfall) and future climate change on the agricultural sector.

Agricultural communities and agricultural stakeholders in ECA need to be able to adjust to climate change and the projected increases in temperature and in rainfall variability. To facilitate this, their ability to cope better with the constraints and opportunities that arise from the seasonal variability in rainfall that is characteristic of current climate must first be enhanced. Rainfed agriculture is and will remain the dominant source of staple food production and the livelihood foundation of the majority of the rural poor in ECA. Large investments in agriculture by a broad range of stakeholders will be required if this sector is to meet the food security requirements of tomorrow's Africa. Many factors contribute to the current low levels of investment, but production uncertainty associated with between- and within-season rainfall variability remains a fundamental constraint to many investors who often overestimate the impact of climate induced uncertainty. Information, tools and approaches are now available that allow for characterization and mapping of the agricultural and pastoral implications of long-term climate change and the development of climate risk management strategies specifically tailored to stakeholders needs (Cooper et al., 2008).

Through this literature review information will be made available on the current state of knowledge on the implications of current climate variability and future climate change on the agricultural sector within ECA. This study will consider evidence of such implications at a range of scales ranging from impacts at the household and community level to those at district, national and regional levels. The study will include an evaluation of the current tools and approaches available to assist in the development of 'climate risk assessment and management frameworks' designed to assist decision making by key stakeholders at all scales.

Chapter 2 will provide some details on the definitions and terminologies related to climate, climate variability and climate change, as these important and are often confused or misused. A general overview will be given about the range of climate adaptation tools and approaches to estimate the impacts of climate change in Chapter 3. Chapter 4 gives some details on the current knowledge on climate variability and climate change in ECA. Chapter 5 elaborates on climate-induced risk and production uncertainty, and its implication for agriculture in ECA, both now and in the future. The implications of climate change on agriculture and pastoralists are discussed in Chapter 6. Options to cope with current climate variability and climate change, in relation to the ASARECA strategic plan are discussed in Chapter 7.

2. Definitions and terminology

While conducting this review, we noticed that a lot of confusion and lack of understanding exists regarding the terminology related to climate and climate change. We therefore provide some basic definitions of and clarifications on some of the terminology used in this report. More details and descriptions can be found in the glossary.

The statistical description of climate is given in terms of means and variability of key weather parameters for a given area over a period of time—usually at least 30 years. This means that the climate of ECA (in terms of rainfall) is defined by the average rainfall and its standard deviation or coefficient of variation. In other words, the season-to-season variation of rainfall that is experienced by, among others, farmers and pastoralists is a characteristic of the prevailing climate. However, it does not represent climate variability (see below) (Cooper et al., 2008).

Climate change refers to any change in climate (as defined above) over time, whether due to natural variability or as a result of human activity. Climate variability refers to the variations in the mean state and other statistics of the climate (see above). This is practically the same as the definition of climate change.

Farming in ECA is largely dependent on rainfed agriculture and therefore has always had to deal with variability in rainfall, especially between- and within-season variability. Farmers and pastoralists in the region therefore are currently dealing with the variability in rainfall that is a characteristic of the current climate, and not of climate variability. This is often confused with climate change. However, this report will argue that for farmers to deal with changes in climate in the future they should enhance their ability to cope better with the constraints and opportunities of current climate variability.

Coping and adaptation are also often confused. Coping refers to strategies that have evolved over time through peoples' long experience in dealing with the known and understood natural variation that they expect in seasons combined with their specific responses to the season as it unfolds. In contrast, adaptive strategies refer to longer-term (beyond a single season) strategies that are needed for people to respond to a new set of evolving conditions (biophysical, social and economic) that they have not previously experienced. The extent to which communities are able to successfully respond to a new set of circumstances that they have not experienced before will depend upon their adaptive capacity. We define adaptive capacity as the ability of people to adjust to new circumstances by individual or collective adaptive strategies for the reduction and mitigation of risk or by changes in practices, processes or structures of systems (Cooper et al., 2008).

Based on those definitions, we need to help farmers cope better with the season-to-season and within-season variability (principally rainfall) that is characteristic of current climates as a prerequisite to adapting to future climate change.

Finally, we distinguish between vulnerability and resilience. Vulnerability refers to the degree to which a system is susceptible to or unable to cope with the adverse effects of climate change, including climate variability and extremes. Vulnerability defines the extent to which climate change may damage or harm a system. Vulnerability depends not only on a system's sensitivity but also on its ability to adapt to new climatic conditions. Resilience, however, refers to the level of disturbance that a system can undergo without crossing a threshold to a situation with different structure or outputs. Resilience depends on ecological dynamics as well as the organizational and institutional capacity to understand, manage and respond to these dynamics.

3. Current climate adaptation tools and approaches to estimate the impacts

A rapidly increasing variety of tools and processes are being developed to improve decision making, reduce risks and generate opportunities associated with climate variability and change. The methods and tools used for impact, vulnerability and adaptation assessment encompass a broad range of applications—from cross-cutting or multidisciplinary (e.g. climate models, scenario-building methods, stakeholder analysis and decision-making tools) to specific sectors (e.g. crop or vegetation models and methods for coastal zone vulnerability assessment) (UNFCCC, 2008). Feenstra et al. (1998) documented methods for impact assessment of and adaptation strategies for climate change and in 2008 UNFCCC compiled a compendium on methods and tools to evaluate impacts of and vulnerability and adaptation to climate change. The latter is a web-based resource that provides key information on available frameworks, methods and tools, and their special features. It is designed to assist in selecting the most appropriate methodology for assessments of impacts and vulnerability, and in preparing for adaptation to climate change.

It goes beyond the objective of this chapter to summarize all tools and approaches available or to create another compendium. This chapter just gives an indication of what kind of tools and approaches are available to estimate the impacts of climate change on the agricultural sector. This chapter is, for the greater part, based on the results of a workshop on climate adaptation tools (IISD, 2007). A brief description of all the tools and approaches mentioned in this chapter is given in Appendix A.

3.1. Information generation, databases and platforms

Current information generation and database tools provide a wide variety of audiences with climate and vulnerability related information. For the most part, the information provides analysis across a wide variety of sectors and scales. Often these are not decision-making tools but rather provide donors, governments and non-governmental organizations with inputs that could be utilized for risk management and adaptation management processes. This category ranges from those databases that use global circulation modelling (GCM) (e.g. PRECIS) to those that use general vulnerability and adaptation data (e.g. NAPA Platform) (IISD, 2007).

The large-scale projections of GCM typically handle horizontal scales of 300 km. For risk management and adaptation management processes these data need to be downscaled to fine scale (high resolution) information. Regional downscaling models can resolve features down to 50 km or less. An example is the regional climate model (RCM). RCM uses GCM to provide grid-scale averages of spatio-temporal hydro-climatic state variables, as well as soil hydrology and thermodynamics and some vegetation dynamic variables. RCM is applicable to multiple scales, sectors and levels of screening but is limited fine/point scale information (UNFCCC, 2008).

Regional climate modelling systems can be applied to any area of the globe to generate detailed climate change projections. An example is 'Providing REgional Climates for Impacts Studies' (PRECIS), developed at the Hadley Centre of the UK Meteorological Office. PRECIS was developed to help generate high-resolution climate change information for as many regions of the world as possible. PRECIS is a typical climate downscaling technique and is just one example of a wide range; other available examples are Statistical DownScaling, Downscaling and MAGICC/SCENGEN (UNFCCC, 2008).

In this report several examples of regional downscaled data are given. Chapter 5 gives examples of projections of climate variables from a range of different models and scenarios. While looking at the implications of climate change on agriculture and pastoralists, spatial data layers are used that are based on regional downscaled data (Chapter 6).

A wide range of historical climate data and near-term forecasting data are available through meteorological offices and through the World Meteorological Organization (WMO) (IIDS, 2007). CLIMWAT, developed by the Food and Agriculture Organization of the United Nations (FAO), is an extensive climatic database of more than 5000 stations worldwide. In Chapter 4, some examples of historical trend analyses are presented.

Besides climate related information, vulnerability related information is required to assess risk management and adaptation management processes. A clear example of a tool that provides governments with inputs that could be utilized for risk management and adaptation management processes is NAPA. The purpose of this tool is to identify the urgent and immediate needs of a country to adapt to the present threats from current variability in rainfall and future climate change. Addressing these needs will expand the current coping range and enhance resilience in a way that will promote the capacity to adapt to current rainfall variability and extremes, and consequently to future climate change. The process is uniquely for LDCs as they have the least capacity to deal with the impacts of climate. It aims to facilitate the delivery of technical assistance to NAPA teams formulating their NAPA documents, particularly with regards to the synthesis of existing vulnerability and adaptation information, and the formulation of relevant adaptation projects profiles. It provides multi-sectoral information aimed at the programme and project level for LDCs within the NAPA process.

In this report NAPA reports for the different countries are compared with a range of intervention options currently promoted by ASARECA to compare the identified urgent and immediate needs to adapt to the current threats from climate change with priorities in agricultural development (Chapter 7).

A wide range of platforms is available to share information and experiences on risk management and adapting to climate change. In various sections of this report reference is made to literature shared on these kinds of platforms. An example is weADAPT, an open platform for sharing information, guidance and experience on assessing and communicating risk and adapting to climate change in multi-stressor environments. The open platform contains core themes on framing adaptation, risk monitoring, decision screening, and communication, as well as tools and methods, and useful guidance to aid adaptation planning and implementation. Another clear example of a framework for capacity building is the global change SysTem for Analysis, Research and Training (START). START fosters regional networks of collaborating scientists and institutions in developing countries to conduct research on regional aspects of environmental change, assess impacts and vulnerabilities to such changes, and provide information to policy makers (IISD, 2007). Various sections of this report refer to information made available through these platforms.

3.2. Computer-based decision tools

Computer-based decision tools are primarily intended to identify climate related risks and to make choices between adaptation options. These tools typically include social vulnerability information and assist in establishing priorities. They also include economic analysis as part of the decision-making process. The tools are designed to incorporate various forms of data and inputs from different stakeholders. The advantage of these models is that they allow the user to easily navigate the platform and thus, rely less on expert knowledge (IISD, 2007).

There is a range of computer-based decision tools available to identify climate related risks and to make choices between adaptation options. Some of these tools create graphs and tables that allow experts to compare the relative strengths of adaptation strategies using both quantitative and qualitative criteria. Other tools are more generally aimed at supporting the decision and policy makers responsible for identifying and appraising the selection and implementation of adaptation measures, taking into account the institutions involved and affected when pursuing given adaptation options. The compendium gives a range of examples of these kinds of decision tools (UNFCCC, 2008).

There is a wide range of sector-specific computer-based decision tools. The agricultural sector tools range from sector-wide economic analyses to farm-level crop models. The crop process models (usually driven by long-term climate data) allow the assessment of the impact of contrasting crop, soil and water management strategies on current climate-induced production risk. They also allow the ex ante assessment of the impact of climate change scenarios on single crops, multiple crops (e.g. APSIM or DSSAT), and entire ecosystems (e.g. CENTURY). Other tools can be used to examine particular ecological factors or processes (e.g. ACRU) or to predict the distribution of plants and other organisms (e.g. CLIMEX, FloraMap or DIVA-GIS). The economic models (e.g. Ricardian analysis and input-output accounting) assist the user to evaluate the economic impacts of changing land values, supply and demand, and commodity production resulting from climate change. There are substantially more agricultural sector tools than there are tools in other sectors. This is because many agricultural models are crop specific or are applicable only to particular regions, whereas models in other sectors tend to be more generally applicable (UNFCCC, 2008). Chapter 5 gives some examples on climate-induced risk and production uncertainty on crops, based on APSIM analyses.

Complex multivariate models attempt to provide a statistical explanation of observed phenomena by accounting for the most important factors (e.g. predicting crop yields on the basis of temperature, rainfall, sowing date and fertilizer application). Statistical models are usually developed on the basis of current variations in rainfall or other weather parameters. One major weakness of this approach is the limited ability to predict effects of climatic events that lie outside the range of current variability. These models may also be criticized for being based on statistical relationships between factors rather than on an understanding of the important causal mechanisms. However, where models are founded on a good knowledge of the determining processes and where there are good grounds for extrapolation, they can be useful predictive tools for climate impact assessment (Feenstra et al., 1998).

In this report, the influence of climate change on the agricultural sector is mainly assessed using GIS, Chapter 6. The application of GIS usually includes: (1) depicting past, present or future climate patterns; (2) using simple indices to evaluate current regional potential for different activities based on climate and other environmental factors; (3) mapping changes in the patterns of potential induced by a given change in climate, thus showing the extent and rate of shifts; (4) identifying regions that may be vulnerable to changes in climate; and (5) considering impacts on different activities with the same geographical region so as to provide a basis for comparison and evaluation (Carter et al., 1994). GIS can be used in conjunction with GCM, biophysical simulation models, and integrated databases to conduct regional and global impact analyses (Feenstra et al., 1998).

3.3. Adaptation/risk management processes

Adaptation/risk management processes are tools developed by specific agencies to screen projects/programmes and/or develop policy priorities. As a result, they are tailored toward the specific decision-making processes of the organization. Similar to computer-based decision tools, they rely on detailed programme/project inputs although they also facilitate greater stakeholder information. Typically, these processes rely on expert advice from their respective climate change departments or outside consultants. They tend to rely more heavily on qualitative inputs while also incorporating climate science information. Some tools incorporate economic analyses where the information is available or where applicable. Generally, these processes take longer than computer-based decision tools but are more thorough in their analysis, providing tailored recommendations for disaster risk reduction and adaptation (IISD, 2007).

Earlier work on climate change impacts and adaptation studies focused more on impacts than on adaptation. The motivation for the research was often driven by the need to understand how great the impacts of climate change might be to know how much urgency to give to the mitigation agenda or the stabilization of greenhouse gas (GHG) concentrations in the atmosphere. Examples of these approaches to the assessment of vulnerability and adaptation are the Intergovernmental Panel on Climate Change (IPCC) Technical Guidelines, the United Nations Environment Programme (UNEP) Handbook, and the US Country Studies Program. These approaches have an analytical thrust and focus on an approach that emphasizes the identification and quantification of impacts (UNFCCC, 2008).

In Chapter 7 of this report the sensitivity of the development domains and intervention options are analysed by assessing the development priorities on vulnerability and current and future climate risks.

4. Climate variability and climate change

Climate change and climate variability are two important characteristics of climatic change. As mentioned in the introduction, climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). According to UNFCCC, climate change is an adjustment of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural variability, observed over comparable time scales. Climate variability refers to the variations in the mean state and other statistics (e.g. standard deviations, the occurrence of extreme events etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Therefore, climate variability is the departure from normal or the difference in magnitude between climatic occurrences.

The climate of Africa is warmer than it was 100 years ago and model-based predictions of future GHG-induced climate change for the continent clearly suggest that this warming will continue and, in most scenarios, accelerate (Hulme et al., 2001; Christensen et al., 2007). Observational records show that during the 20th century the continent of Africa has been warming at a rate of about 0.05°C per decade with slightly larger warming in the June–November seasons than in December–May (Hulme et al., 2001).

The data in Figure 1 show the mean temperature anomalies for the last 100 years for Africa. By 2000, the five warmest years in Africa had all occurred since 1988, with 1988 and 1995 being the two warmest years. This rate of warming is not dissimilar to that experienced globally, and the periods of most rapid warming—the 1910s to 1930s and the post-1970s—occurred simultaneously in Africa and the rest of the world (IPCC, 2001).

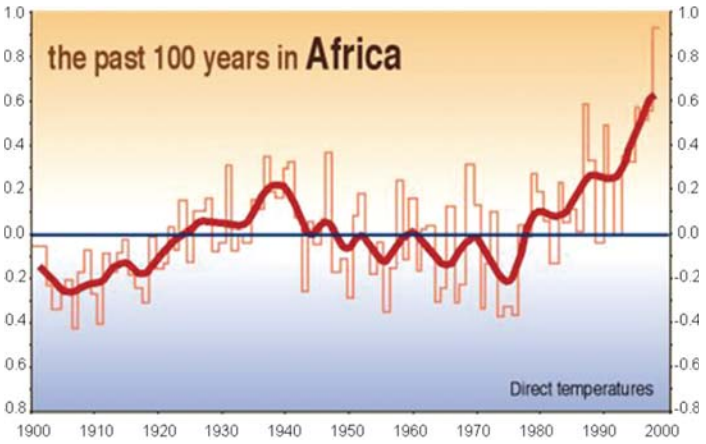


Figure 1. Temperature trends: mean temperature anomalies in °C for the last 100 years for Africa (IPCC, 2001).

The projections for rainfall are less uniform (Figure 2). Hulme et al. (2001) illustrate the large regional differences that exist in rainfall variability. East Africa appears to have a relatively stable rainfall regime, although there is some evidence of long-term wetting. Similarly, there is likely to be an increase in annual mean precipitation in East Africa (Christensen et al., 2007).

Many of the impacts of climate change will materialize through changes in extreme events such as droughts and floods. Such extremes result in severe human suffering, and hamper economic development and efforts at poverty reduction. Unfortunately, assessments of climate change are often limited to mean temperature and precipitation. Knowledge of changes in extremes is sparse, particularly for Africa. In some regions, different models project different trends in wet and dry extremes. In other regions, however, models show clear trends such as increasing drought in the Kalahari and increasing floods in East Africa (KNMI, 2006).

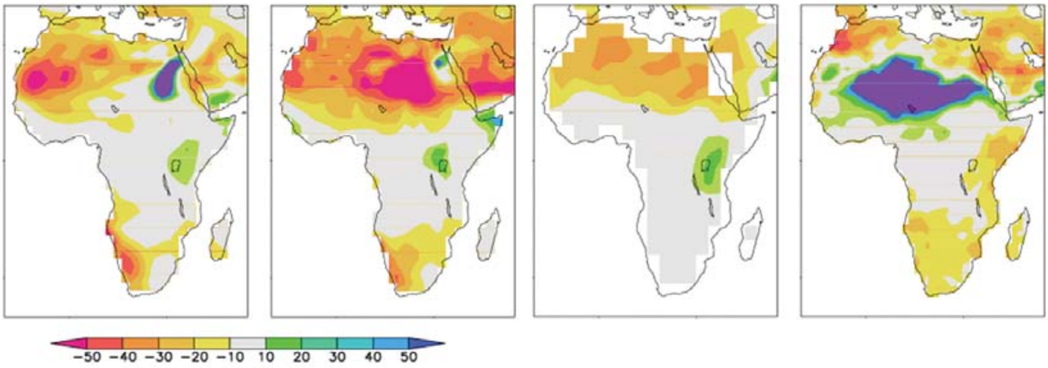


Figure 2. Percentage change in annual mean precipitation around 2050 compared with 1971–2000 in selected climate models, from left to right: GFDL (CM2.0 & CM2.1), CCCMA, CGCM3.1 and HadGEM1 (KNMI, 2006).

4.1. Current climate characteristics

In ECA large water bodies and varied topography give rise to a range of climatic conditions, from a humid tropical climate along the coastal areas to arid low-lying inland elevated plateau regions across Ethiopia, Kenya, Somalia and Tanzania. The presence of the Indian Ocean, Lake Victoria and Lake Tanganyika, as well as high mountains such as Kilimanjaro and Kenya induce localized climatic patterns in this region (KNMI, 2006). Mean temperature varies with elevation. In Figure 3 the difference between the lowest minimum and maximum temperatures for highland regions is in the order of 8–10°C.

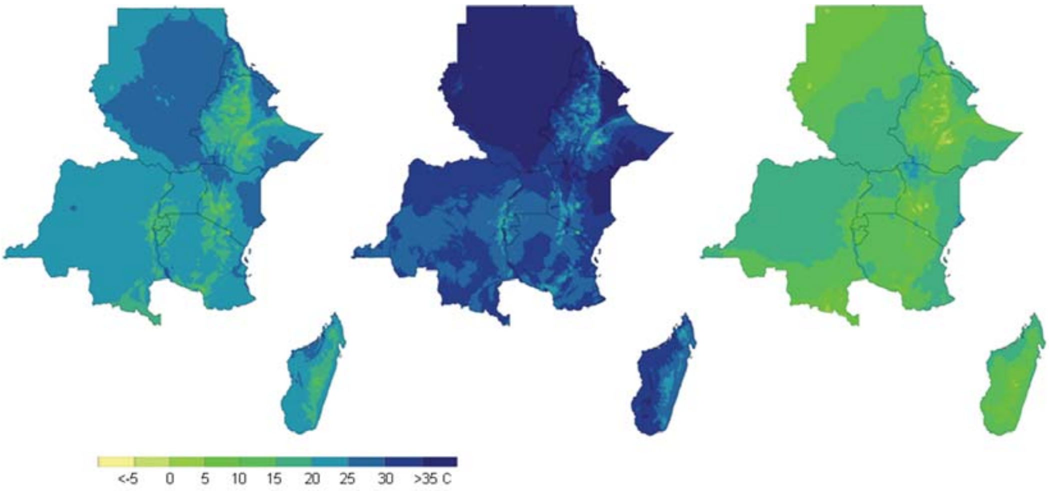


Figure 3. Current conditions for temperature (2000), from left to right: the mean average of monthly data on temperature, maximum temperature of warmest month, and minimum temperature of coldest month (Hijmans et al., 2005).

As ECA lies astride the equator, much of the region experiences a bimodal seasonal pattern: the long rainy season starts around March and runs through to June, with the peak centred on March to May; the short rains run from September and taper off in November or December (coinciding with the shifting of the Inter-Tropical Convergence Zone). Areas south of about 5°S have a single rainy season with most rainfall received during austral summer (KNMI, 2006). The annual rainfall and the coefficient of variation of annual rainfall (the standard deviation of annual rainfall divided by the mean expressed as a percentage) at a resolution of 10 arc-minutes are shown in Figure 4. The rainy seasons can be extremely wet and often late or sudden, bringing floods and inundation (Anyah and Semazzi, 2007). Links between El Niño events and climate variability have been suggested, and it is a common perception that high coefficients of variation in rainfall may be attributed to El Niño effects (Anyah and Semazzi, 2007). However, currently it is not clear whether a relationship exists between both El Niño or La Niña events and prolonged drought or particularly wet periods over much of the Greater Horn of Africa (Thornton et al., 2006; Conway et al., 2007).

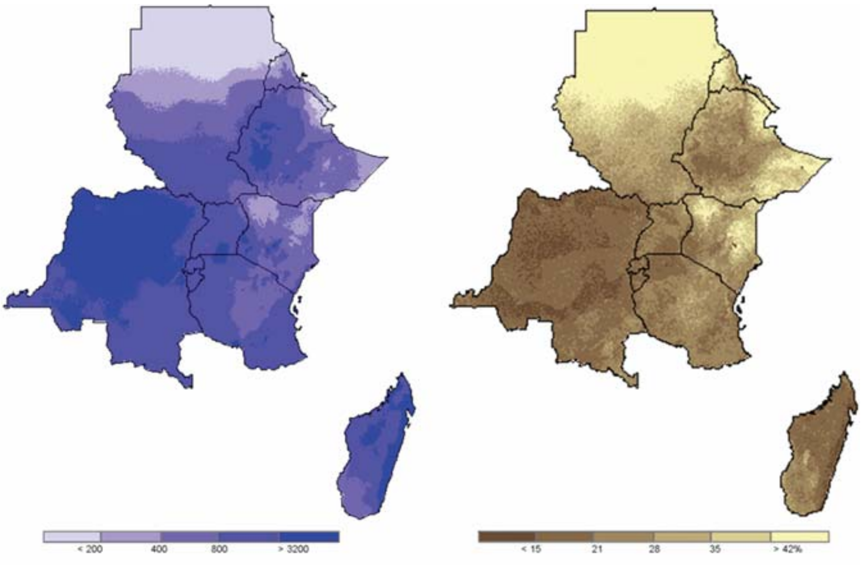


Figure 4. Current conditions for rainfall (2000), from left to right: the mean annual rainfall and the variation of annual rainfall (Hijmans et al., 2005).

4.2. Projected changes in temperature and precipitation

Climate change scenarios are most commonly derived from the results of GCMs. These models are parameterized to represent the dynamics of the atmosphere under current conditions. They are then rerun at graduated atmospheric concentrations of carbon dioxide to simulate future conditions. Differences that develop between simulation runs in temperature, rainfall, evapotranspiration and other climatic factors are reported as predictors of climate change (Schlesinger and Mitchell, 1985). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007a) indicates that climate model projections for the period between 2001 and 2100 suggest an increase in global average surface temperature of between 1.1°C and 6.4°C, the range depending largely on the scale of fossil-fuel burning within the period and on the different models used. Since the first IPCC report in 1990, assessed projections have suggested global average temperature increases between about 0.15°C and 0.3°C per decade for 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections (IPCC, 2007a). The climate model simulations under a range of possible emissions scenarios suggest that for Africa in all seasons, the median temperature increase lies between 3°C and 4°C, roughly 1.5 times the global mean response. Half of the models project warming within about 0.5°C of these median values (Christensen et al., 2007). This is illustrated for regions of sub-Saharan Africa in Table 2. The summary output of 21 GCMs used by IPCC in their latest report to predict the annual changes in temperature and rainfall that will occur by the end of the 21st century is presented in

Table 2. Maximum and minimum predictions of change are given together with the 25, 50 and 75 quartile values from the 21 GCMs (Cooper et al., 2008). Whilst all models agree that it will become warmer, the degree of warming predicted is quite variable.

Table 2. Regional predictions for climate change in Africa by the end of the 21st century

Region	**Season**	**Temperature response (°C)**				**Precipitation response (%)**					
		Min	25	50	75	Max	Min	25	50	75	Max
West Africa	DJF	2.3	2.7	3.0	3.5	4.6	-16	-2	6	13	23
	MAM	1.7	2.8	3.5	3.6	4.8	-11	-7	-3	5	11
	JJA	1.5	2.7	3.3	3.7	4.7	-18	-2	2	7	16
	SON	1.9	2.5	3.3	3.7	4.7	-12	0	1	10	15
	Annual	1.8	2.7	3.3	3.6	4.7	-9	-2	2	7	13
East Africa	DJF	2.0	2.6	3.1	3.4	4.2	-3	6	13	16	33
	MAM	1.7	2.7	3.2	3.5	4.5	-9	2	6	9	20
	JJA	1.6	2.7	3.4	3.6	4.7	-18	-2	4	7	16
	SON	1.9	2.6	3.1	3.6	4.3	-10	3	7	13	38
	Annual	1.8	2.5	3.2	3.4	4.3	-3	2	7	11	25
Southern Africa	DJF	1.8	2.7	3.1	3.4	4.7	-6	-3	0	5	10
	MAM	1.7	2.9	3.1	3.8	4.7	-25	-8	0	4	12
	JJA	1.9	3.0	3.4	3.6	4.8	-43	-27	-23	-7	-3
	SON	2.1	3.0	3.7	4.0	5.0	-43	-20	-13	-8	3
	Annual.	1.9	2.9	3.4	3.7	4.8	-12	-9	-4	2	6

Note: DJF = December, January and February; MAM = March, April, May, JJA = June, July and August; SON = September, October, November.
(IPCC, 2007a)

For precipitation, the situation is more complicated. Precipitation is highly variable spatially and temporally, and data are limited in some regions (IPCC, 2007a). As indicated by Sivakumar et al. (2005) rainfall changes in Africa projected by most GCMs are relatively modest, at least in relation to current rainfall variability. Seasonal changes in rainfall are not expected to be large. Great uncertainty exists, however, in relation to regional-scale rainfall changes simulated by GCMs. The problem involves determining the character of the climate change signal on African rainfall against a background of large natural variability compounded by the use of imperfect climate models (Sivakumar et al., 2005). In ECA there are very few places where rainfall means are likely to decrease (Thornton et al., 2006). The increase in rainfall in East Africa, extending into the Horn of Africa, is robust across the ensemble of GCMs, with 18 of 21 models projecting an increase in the core of this region, east of the Great Lakes (Christensen et al., 2007).

Hulme et al. (2001) discusses two fundamental reasons why there is much less confidence about the magnitude, and even direction, of regional rainfall changes in Africa. Two of these reasons relate to the rather ambiguous representation of climate variability in the tropics in most GCMs, for example of El Niño Southern Oscillation (ENSO), which is a key determinant of African rainfall variability. Another reason is the omission in all current global climate models of any representation of dynamic land cover–atmosphere interactions. Such interactions have been suggested to be important in determining African climate variability during the Holocene and may well have contributed to the more recently observed desiccation of the Sahel (Hulme et al., 2001).

4.3. Projected changes in extreme events

As stated in the Millennium Ecosystem Assessment (2005) natural hazards and disasters are products of both natural variability and human–environment interactions. The extremes of the variability are defined as hazards when they represent threats to people and what they value and defined as disasters when an event overwhelms local capacity to cope. It is well established that the impacts of natural disasters continue to create uneven patterns of loss in populations around the world. Considering lack of resources and capacity to prevent or cope with the impacts, it is clear that the poor are the most vulnerable to natural disasters. Abramovitz (2001) argues that although the absolute losses of natural disasters are far larger for rich nations, the effect of natural disasters is greater on poorer nations. This becomes very clear when looking at the effect expressed as losses as percentage of GDP (Figure 5). Therefore it is important to look at the predictions of extreme events that could lead to natural disasters.

Research on changes in extremes specific to Africa, in either models or observations, is limited. Little can be said yet about changes in climate variability or extreme events in Africa (Sivakumar et al., 2005; Christensen et al., 2007). A general increase in the intensity of high-rainfall events, associated in part with the increase in atmospheric water vapour, is expected in Africa, as it is in other regions (Christensen et al., 2007). The increase in the number of extremely wet seasons is increasing to roughly 20% (i.e. 1 in 5 of the seasons are extremely wet, as compared to 1 in 20 in the control period in the late 20th century) (Christensen et al., 2007). Dry extremes are projected to be less severe than they have been during September to December but the GCMs do not show a good agreement in the projected changes of dry extremes during March to May (Thornton et al., 2006; KNMI, 2007). Most climate models simulate drier conditions during the

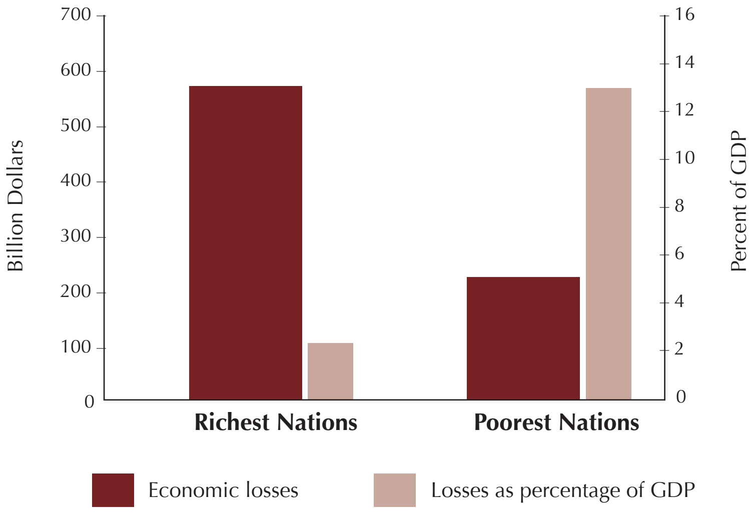


Figure 5. Disaster losses, total and as share of GDP, in ten richest and poorest countries, 1985–1999 (Abramovitz, 2001).

21st century in eastern Sudan and in Ethiopia. This drying was prevalent during the last decades of the 20th century in these regions. There is little consensus among the models with respect to their simulated changes in extreme rainfall events. A spatially coherent pattern is the increase in 10-year highest rainfall events over northern Somali and the Horn of Africa, and more severe dry events over the same areas. Thus extreme events are likely to become more intense over much of the north-east of ECA, particularly over the east (KNMI, 2006).

Over much of Burundi, Kenya, Rwanda, southern Somalia and Uganda there are indications of an upward trend in rainfall under global warming. Wet extremes (defined as high rainfall events occurring once every 10 years) are projected to increase during both the September to December rainy season and the March to May rainy season, locally referred to as the short and long rains respectively. Dry extremes are projected to be less severe in the northern parts of the region during September to December, but the models do not show a good agreement in their projected changes of dry extremes during March to May (Thornton et al., 2006). KNMI (2006) shows the projected variations in wettest events that occur once every 10 years on average. It should be kept in mind that climate models all underestimate the strength of the long rains in the current climate, limiting the confidence of these projections (KNMI, 2006; Thornton et al., 2006). KNMI (2006) uses 12 models, on the basis of the realism with which they represent the observed 20th century pattern of African precipitation variation (inter-annual variability and its amplitude). For those models, KNMI investigated the likely changes in precipitation (mean and extremes) using the runs forced with the Special Report Emission Scenario (SRES) A1B scenario.

North-east Africa

A preponderance of the evidence from the model projections supports an increase in the intensity of 10-year highest rainfall events in the Greater Horn of Africa (Figure 6). Over Ethiopia and eastern Sudan the uncertainty is larger as the models behave differently with respect to their simulated changes in wet extremes. Despite the projected downward trends in long-term rainfall means, the intensity of extreme rainfall events is projected to rise over the Horn (KNMI, 2006).

Over the same areas where the models predict more intense wet extremes (in the Greater Horn of Africa), indications are for more severe dry conditions as well in future climates (Figure 7). The implication therefore is that in these areas the rainfall distribution will be more diffuse (larger variance of monthly rainfall) in future.

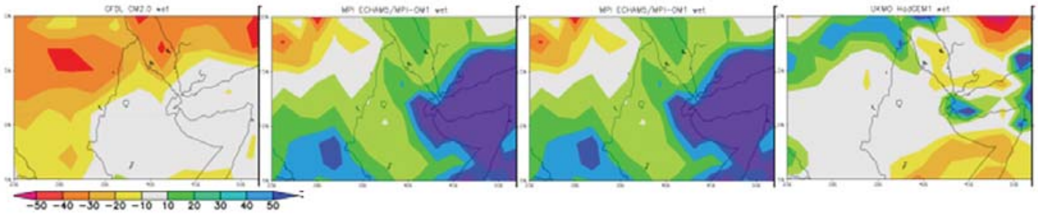


Figure 6. Percentage changes in the amount of rainfall around 2100 in high rainfall events that occur once every 10 years on average. From left to right GCM: GFDL (CM2.0 & CM2.1), MPI ECHAM5, and UKMO HadGEM1 (KNMI, 2006).

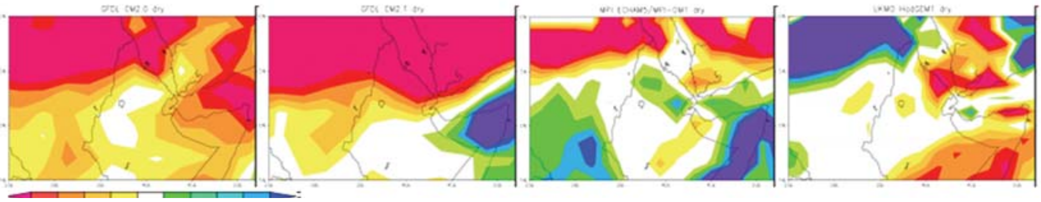


Figure 7. Percentage changes in the amount of rainfall around 2100 in low rainfall events that occur once every 10 years on average. From left to right GCM: GFDL CM2.0, GFDL CM2.1, MPI ECHAM5, and UKMO HadGEM1 (KNMI, 2006).

East Africa

Over much of Burundi, Kenya, Rwanda, southern Somali and Uganda there are indications of an upward trend in rainfall under global warming. Wet extremes (defined as high rainfall events occurring once every 10 years) are projected to increase during both the short (September to December) and long (March to May) rains. In general, a positive shift in the whole rainfall distribution is simulated by the models over most of East Africa during both rainy seasons (KNMI, 2006).

Short-rains (September–December)

In the warmer climate around 2100, the GCMs show evidence of an increase in the intensity of extreme rainfall events in much of East Africa, notably in Burundi, Kenya, Rwanda, southern Somali and Uganda. During the short rains, there are indications of the possibility of increases in excess of 50% in 10-year high rainfall events over the north of East Africa. In southern Tanzania the wettest rainfall events are projected to decrease by 0% to 20% (Figure 8) (KNMI, 2006).

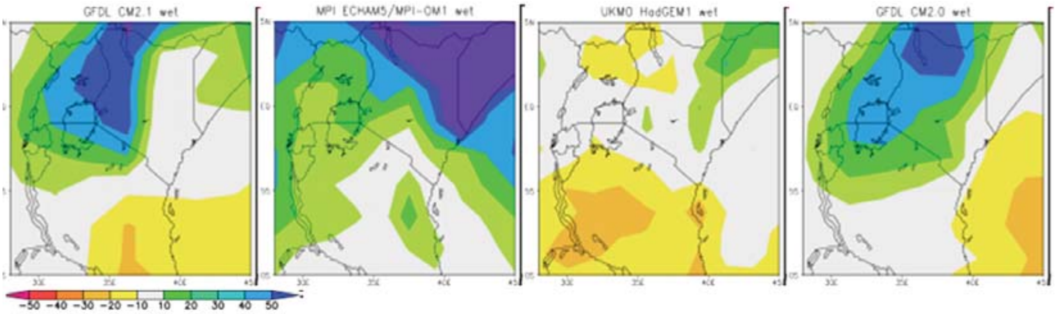


Figure 8. Percentage changes in the amount of rainfall around 2100 in short rains high rainfall events that occur once every 10 years. From left to right, GCM: GFDL CM2.1, MPI ECHAM5, UKMO HadGEM1, and GFDL CM2.0 (KNMI, 2006).

Simulated changes in low-rainfall extremes (Figure 9) show that these events are becoming less severe in Burundi, Rwanda, Uganda, northern Kenya and southern Somali during the September to December season in the most realistic models (with the exception of the Rift Valley in HadGEM1). The simulated increase is far more than 50% in certain parts of the region. Noting that increases in both the wettest and the driest rainfall events have been found over the same areas, this shows an overall shift in the rainfall distribution, with floods becoming more likely than the opposite extreme (KNMI, 2006).

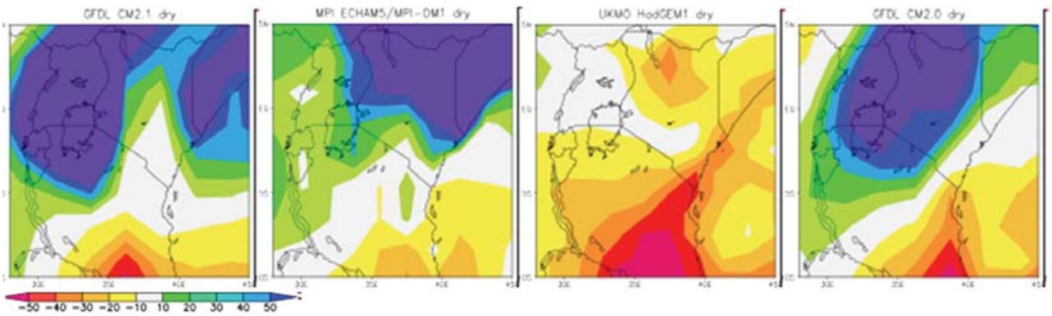


Figure 9. Percentage changes in the amount of rainfall around 2100 in short rains lowest rainfall events that occur once every 10 years. From left to right GCM: GFDL CM2.1, MPI ECHAM5, UKMO HadGEM1, and GFDL CM2.0 (KNMI, 2006).

Long-rains (March-May)

Even during the long rains, the GCMs continue to simulate an increase in the 10-year highest rainfall events in large parts of East Africa (Figure 10). Over north-eastern Kenya and southern Somali during this season only HadGEM1 does not simulate large increases in the amount of rain in extremely wet seasons. Over southern Tanzania, most models give an indication of an increase in high rainfall events. Thus, while some models show an increase in the severity of extremely low rainfall events in northern Kenya, others simulate a decrease over the same areas. However, these climate models all severely underestimate the strength of the long rains in the current climate, limiting reliability of these projections (KNMI, 2006).

However, there is no consensus between the GCMs on the likely changes in the severity of dry events (Figure 11). While some models show an increase in the severity of extremely low rainfall events in northern Kenya, others simulate a decrease over the same areas. Since the model simulations of the 20th century climatology during this season are inaccurate, model projections of future climate during this season are currently unreliable (KNMI, 2006).

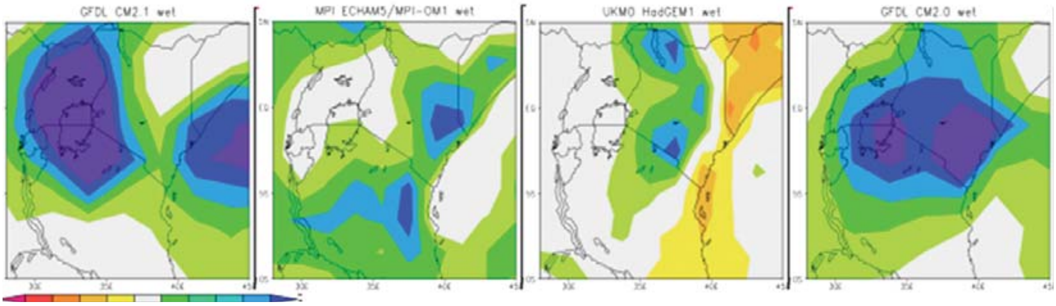


Figure 10. Changes in the amount of rainfall around 2100 in long-rains high rainfall events that occur once every 10 years. From left to right GCM: GFDL CM2.1, MPI ECHAM5, UKMO HadGEM1, and GFDL CM2.0 (KNMI, 2006).

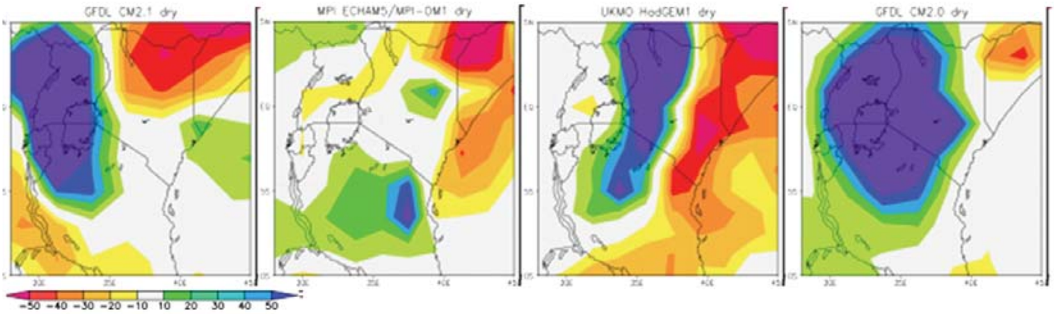


Figure 11. Changes in the amount of rainfall around 2100 in long rains lowest rainfall events that occur once every 10 years. From left to right GCM: GFDL CM2.1, MPI ECHAM5, UKMO HadGEM1, and GFDL CM2.0 (KNMI, 2006).

4.4. Uncertainties and limitations to knowledge

The future is of course inherently unknown and unpredictable. In relation to climate change in general, there are two overarching areas of uncertainty (Thornton et al., 2008). One relates to the nature of human development in the coming decades, and the second to what is actually knowable about the climate system and how it will respond to activities of human and the other drivers that govern it. Thornton et al. (2008) indicated that the first of these is often dealt with using scenarios of the future, or 'plausible futures'—different sets of assumptions about how human development will proceed in the future, linked to global drivers such as economic growth, technological change, population growth etc. A lot of work has been done on scenario development. There are several reasons for this, including identifying knowledge gaps, understanding the significance of uncertainties, illustrating what is possible and what is not possible, and identifying what strategies might work in a range of possible scenarios. The emission scenarios of the IPCC are just one example.

The second overarching area of uncertainty, the issue of what is actually knowable about the climate system and how it will respond to the drivers that govern it, is in many ways more problematic (Thornton et al., 2008). There are various sources of uncertainty with regard to climate projections. Over several decades, some of this uncertainty arises because it is unknown how the future is influenced by, e.g. solar output, volcanic eruptions, rates of ocean heat uptake, and human activity affecting the composition of the atmosphere and feedback from the land surface (Wilby, 2007). Over the next four decades, global mean temperature rise is largely insensitive to differences among emission scenarios (Stott and Kettleborough, 2002).

Hulme et al. (2001) pointed out that climate change scenarios for Africa based on GHG warming remain highly uncertain because of: (1) the problem of small signal-to-noise ratios in some scenarios for precipitation and other variables; (2) the inability of climate model projections to account for the influence of land cover changes on future climate; and (3) the relatively poor representation in many models of some aspects of climate variability that are important for Africa (e.g. ENSO). Moreover, vegetation feedback and feedback from dust aerosol production are not included in the global models, and there is insufficient information on which to assess possible changes in the spatial distribution and frequency of tropical cyclones affecting Africa (IPCC, 2007a). The IPCC report (2007a) stresses that further research is critical to understanding how possible climate-regime changes (e.g. ENSO events) may influence future climate variability.

It is evident that present and future predictability of climate change is not the same everywhere, and that gaps in knowledge of basic climatology are revealed by a lack of agreement between climate models in some regions (Wilby, 2007). While there is now higher confidence in projected patterns of warming and sea-level rise, there is less confidence in projections of the numbers of tropical storms and of regional patterns of rainfall over large areas of Africa (Thornton et al., 2008).

Thornton et al. (2008) mentioned that there are at least two more problems associated with current knowledge of climate and climate modelling. The first has a direct bearing on our lack of understanding of what the local-level impacts of climate change are likely to be. This relates to the uncertainties involved in downscaling GCM output to the high spatial resolutions needed for effective adaptation work. It is not that this downscaling cannot be done, it is just that its adequacy cannot currently be evaluated objectively (Thornton et al., 2008). Very few regional to sub-regional climate change scenarios using regional climate models or empirical downscaling have been constructed for Africa mainly due to restricted computational facilities and lack of human resources and problems of insufficient climate data (Boko et al., 2007; Christensen et al., 2007). The extent to which current regional models can successfully downscale precipitation over Africa is unclear, and limitations of empirical downscaling results for Africa are not fully understood. It is evident that present and future predictability of climate variability and change is not the same everywhere and those gaps in knowledge of basic climatology are revealed by a lack of agreement between climate models in some regions (Wilby, 2007).

The second problem relates to the significant gap that exists between the information that we currently have at seasonal time scales and the information we have at ‘climate change’ time scales (2050 and beyond)—information about what is likely over the next 3 to 20 years is largely missing (Washington et al., 2006). This presents a critical problem, as this time scale is vital for political negotiation, for assessing vulnerability and the relationship with the Millennium Development Goals, and for agricultural planning. While users of climate risk information are most interested in the next few decades, the global climate of the coming decades will be dominated by natural variations from year to year and from decade to decade arising from the chaotic nature of ocean–atmosphere interactions, changes in the output of the sun, and the amount of aerosol injected into the stratosphere by explosive volcanic eruptions (Wilby, 2007). The human signal, though detectable and growing, is a relatively small component of the variability that can be expected in the short term.

It is likely to be many years before these issues are addressed satisfactorily. Climate science has a long way to go. In the meantime, there are various things that can be done: the development of the scientific and economic capacity to better understand and cope with current variability in rainfall (Washington et al., 2006); and the development of climate forecast tools and data sets that capture incremental changes in risk over the scales needed for adaptation planning (Wilby, 2007). Unfortunately, the current limits to prediction constitute a substantial stumbling block in understanding local impacts of climate change over the short to medium term and thus in assessing the efficacy and appropriateness of different adaptation and mitigation options in specific situations (Thornton et al., 2008).

5. Climate-induced risk and production uncertainty

5.1 Climate induced risk, a constraint to adoption of innovation and investment

ASARECA's mandate is to provide integrated research support to rainfed agricultural and pastoral systems in ECA. In recent decades, however, investment and growth in rainfed agriculture in the region (and Africa as a whole) has stagnated. There are many inter-related issues that contribute to the current lack of investment and the resultant stagnation of rainfed production in sub-Saharan Africa. The Green Revolution that made dramatic contributions for improving agricultural productivity and reducing poverty in Asia and Latin America has largely by-passed sub-Saharan Africa. The outcomes of lack of investment and stagnation of agricultural production reinforce each other leading to poverty traps and vulnerability of livelihoods to climatic and other shocks (Reardon and Vosti, 1995; Collier and Gunning, 1999). The market-led innovation model of agricultural transformation (Ruttan and Hayami, 1998) did not materialize in sub-Saharan Africa mainly because of the interplay of market and policy failures (World Bank, 2008).

Agricultural investment by smallholder farmers in risk-prone environments has occurred to some extent over the last few decades (LSE, 2001). For them to blossom and produce the needed impact, favourable policies, institutional arrangements and basic development infrastructure (including irrigation, roads, electricity and ICT) are needed for proper functioning of markets. An enabling investment policy environment would thus include the existence of proper incentives, market access, information, input supply systems and institutions (Barrett et al., 2002). Low per capita incomes, debt servicing and negative balance of payments at the national level have undermined the ability of governments to invest in basic infrastructure needed for markets and the private sector to operate efficiently and effectively. These issues all impinge on investment decisions taken by a range of stakeholders within the rainfed agricultural sector (Shiferaw et al., 2009).

One underlying and fundamental characteristic of rainfed agriculture that cannot be ignored is the current rainfall variability both within and between seasons and the inevitable uncertainty that it imposes on farm production and the rates of return that farmers receive from investing in innovative farming practice.

This challenging scenario is coupled with the accepted prediction that, global warming and the inevitable changes to rainfall patterns are likely to exacerbate existing rainfall variability and further increase the frequency of climatic extremes.

This climate-induced uncertainty discourages beneficial 'investment' decisions required, not only from farming communities, but also from a wide range of additional agricultural stakeholders. Farmers, their supply agents and stakeholders often over-estimate the negative impact of climate induced risk (Figure 12). As a result, they show understandable reluctance to invest in potentially more sustainable, productive and economically rewarding practices when the returns to investment appear so unpredictable from season to season.

Over generations, and especially in the more arid environments where rainfall variability has the most impact on livelihoods, farmers and pastoralists have developed coping strategies to buffer against the uncertainties induced by season-to-season variation in water supply and the socio-economic drivers which impact on their lives.

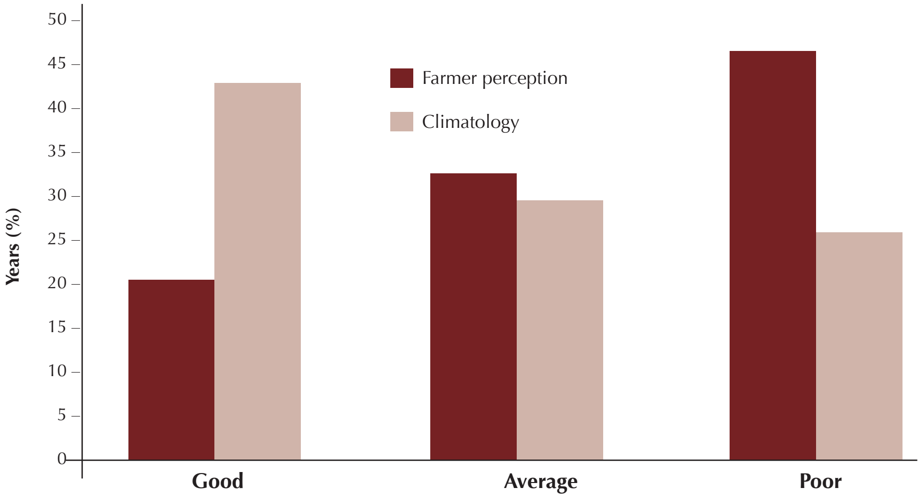


Figure 12. Farmers' perceptions of frequency of good, average and poor seasons in Kenya compared with the reality of long-term climate data.

Depending on their assessment of risks and vulnerability, farming households make certain choices and adjustments in their technologies, production and consumption decisions. Such coping strategies can be broadly grouped into three categories (e.g. Matlon and Kristjanson, 1988):

1. *Ex ante* risk management options such as choice of risk-tolerant varieties, investment in water management, and diversification of both farming and other associated livelihood enterprises before the onset of the season.

2. In-season adjustment of crop and resource management options in response to the nature of the rainfall season as it unfolds.
3. *Ex post* risk management options that minimize livelihood impacts of adverse climatic shocks (e.g. distress selling of assets, borrowing and cutting expenditures on non-essential items).

In drier environments, where cropping is largely impossible, pastoralism dominates. In such environments coping strategies assume even greater importance, but are perhaps less diversified due to the more restricted resource base. McIntire (1991) notes that mixed species herds, widespread and seasonally available pastures, splitting animals into discrete herds and mobility in response to seasonal variation in pasture productivity are key strategies. Where the opportunities exist, working as wage labourers, trading commodities and growing crops are also common.

Whilst such coping strategies enable rainfed farming families and pastoralists to survive, they are risk avoiding in nature. They are designed to mitigate the negative impacts of the poorer seasons, but fail to exploit the positive opportunities of the ‘average’ and ‘better than average’ seasons. As a result, most families remain poor and susceptible to further climatic variability and shocks.

Against this background, a wealth of information has emerged over recent decades in ECA that has identified a broad range of crop, soil, water and biodiversity management innovations. Each of them is affected to some extent by the variable rainfall characteristics of any given season. One simple question that has seldom been asked and addressed is: ‘how many years out of 10 will any given innovation provide rates of return that are acceptable to risk averse farmers?’. The answer to this question will go a long way in providing information necessary to support acceptable innovations.

However, climate induced production risk can now be quantified using a range of new and proven tools and approaches. There is also increasing evidence that the quantification of such risk and its management can greatly support the decision-making process of farmers who are risk averse to enhance the adoption of more sustainable and productive farming practice (Cooper et al., 2008).

At one level of analysis, research can focus on the probability of climatic events of known importance to farmers and their support agents such as the start of the growing season, the frequency of dry spells within the season, the frequency of high intensity erosive rainfall events or the length of the growing season itself (Sivakumar, 1988). A further step is the use of simulation models that integrate the impact of variable weather with a range of soil, water and crop management choices. Such simulation models, usually driven by daily climatic data, can be used to predict the impact of season-to-season rainfall and temperature variability on the probability of success of a range of crop, water and soil management strategies. The use of such models, with long runs (30 years or more) of daily climatic data can provide substantial added value to ongoing and future agronomic and crop research within ECA. One such model that is being increasingly used in sub-Saharan Africa is the Agricultural Productions Systems Simulator (APSIM). APSIM can simulate various soil and water management practices together with the growth and yield of a range of crops that are of importance in ECA. When properly calibrated for these crops, APSIM provides an accurate simulation of actual crop yields across a range of soil types and seasons (Dimes, 2005). In addition, because these types of models are driven by climate data, they can also be used to evaluate the implications of climate changes (e.g. Abraha and Savage, 2006; Walker and Schultze, 2008).

5.2 Some case studies of climate induced risk analyses

In this section some examples are provided which illustrate how climate-induced risk analyses can add value to ASARECA's research agenda. It is beyond the scope of this chapter to provide an exhaustive review of past and ongoing research in climate risk management research, and the examples that we provide are only intended to illustrate what is possible.

A long-term daily climatic data analysis from Makindu in Kenya was done. In this study the current season-to-season variability of single or a combination of weather events that are known to be important with regard to their implications for rainfed crop, pasture and livestock production is examined. The extent to which any trends have emerged over time which indicate a change in such key aspects of the climate also examined.

Then, using climate driven crop growth simulation models, some examples from Makindu and Masvingo (Zimbabwe) are provided which illustrate how such day-to-day and season-to-season variability in climatic parameters combine to influence the risk associated with crop, soil and water management innovations that are currently being recommended to small-scale farmers.

Finally, an analysis that examines the impact of drought frequency and possible changes in that frequency due to climate change on the livestock assets of pastoralists in Kajiado, Kenya, is presented.

Variability and trends of important weather events at Makindu, Kenya

Mean air temperatures are important in influencing a range of crop processes, such as the rates of crop development, photosynthesis and evapotranspiration. We present the season-to-season variation of the mean maximum and mean minimum air temperatures for the 'short' rainy season at Makindu, namely for the months of October, November and December (Figure 13).

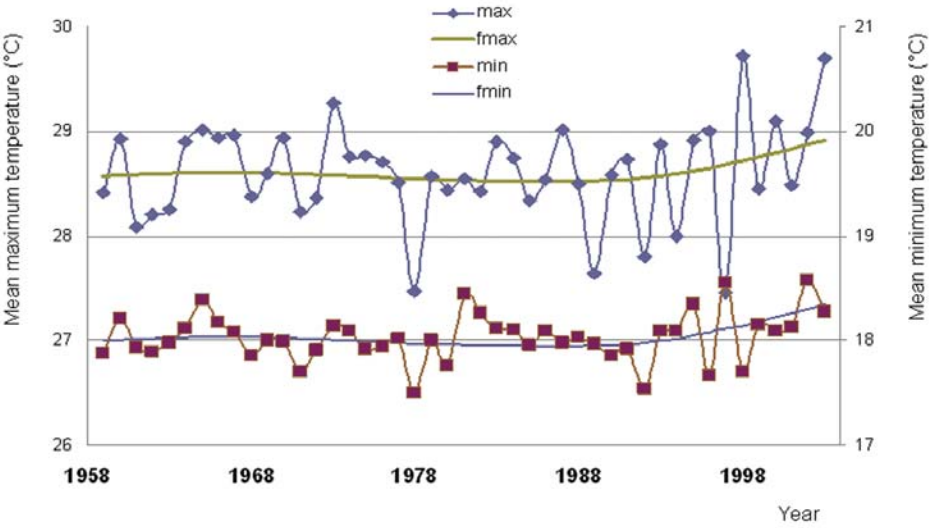
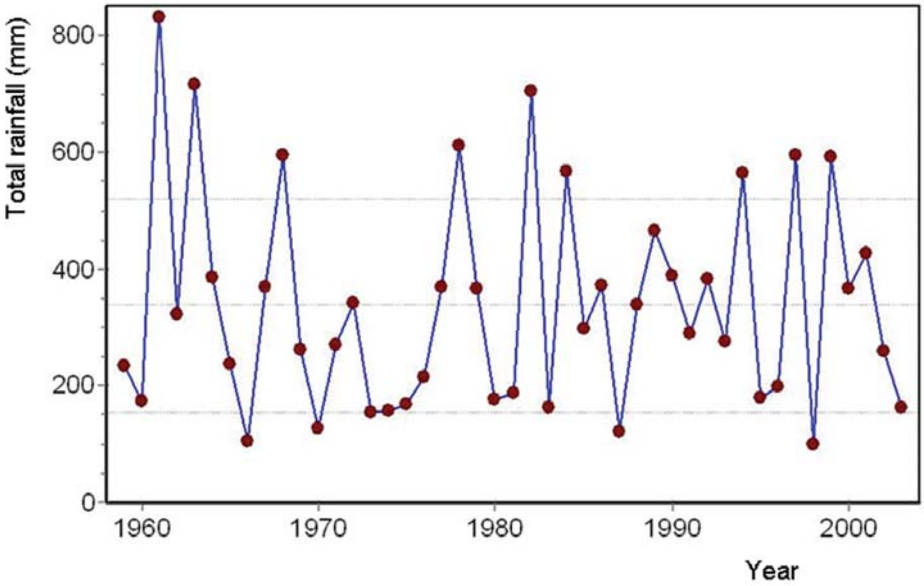


Figure 13. Mean maximum and mean minimum temperatures for the short rainy season (October, November, December) at Makindu, Kenya (1959–2004).

As is characteristic of all such analyses, there is considerable variation in the mean maximum and the mean minimum temperatures from season to season, and interestingly (as observed in other analyses), an increase in temperature, in this instance from about 1990 onwards. These variations and possible trends are important. Other studies (Cooper et al., 2009) have shown that a 1°C rise in mean temperature causes a 5% decrease in the days to maturity of the maize variety Katumani Composite B and a 6% decrease for short duration pigeon pea grown with corresponding reductions in grain yield.

Rainfall amounts and distribution are of paramount importance to ASARECA's mandate for rainfed agriculture. We illustrate several aspect of this, again for the short rainy season at Makindu only. Using INSTAT software, we started by simply looking at the season-to-season variability of rainfall totals (Figure 14).

As expected, there is great variability in rainfall totals (<150 mm to >800 mm) with a mean of 370 and standard deviation of 180 mm (CV of 49%). As we show later, this is clearly reflected in the climate-induced production risk of crops grown in these environments and is fundamental



Note that the horizontal lines show mean (370 mm) and standard deviation (180 mm) from the mean.

Figure 14. Seasonal rainfall totals for the short rainy season (October, November, December) at Makindu, Kenya (1959–2004).

in shaping farmers' risk-averse strategies. Regression lines were fitted to check for evidence of climate change. There were no trends that approached statistical significance, and the proportion of variation explained by the line was less than 1%. The actual slope was -0.33 mm per year for the rainfall totals.

We also present further analyses which looked in more detail at characteristics of rainfall patterns, namely the number of rainy days per season from the perspective of: (i) the number of days when rainfall >0.85 mm was recorded; and (ii) the number of days on which more than 15 mm (likely to be erosive events) was recorded (Figure 15).

There was an average of 24 rain days per season in the 3 months, i.e. about 8 days per month, of which one-third of the days had potentially erosive events of 15 mm or more. As would be expected, there again exists great variation in the mean values. There were no trends that approached statistical significance in either of these variables, and the proportion of variation explained by the line was less than 1%. The actual slope was +0.04 rain days per season for both.

Variability in rainfall amounts and distribution patterns will clearly influence the answer to a question that is perhaps the single most important for risk-averse farmers, namely 'when should I plant my crop without the risk of subsequent crop failure?'. We examined this using INSTAT by assuming that if there was 15 mm of rainfall within a 3-day period, then that would trigger planting. In a second analysis we added the caveat that this was only safe to do as long as it was not followed by a 12-day dry spell. The results of our analysis are given in Figure 16.

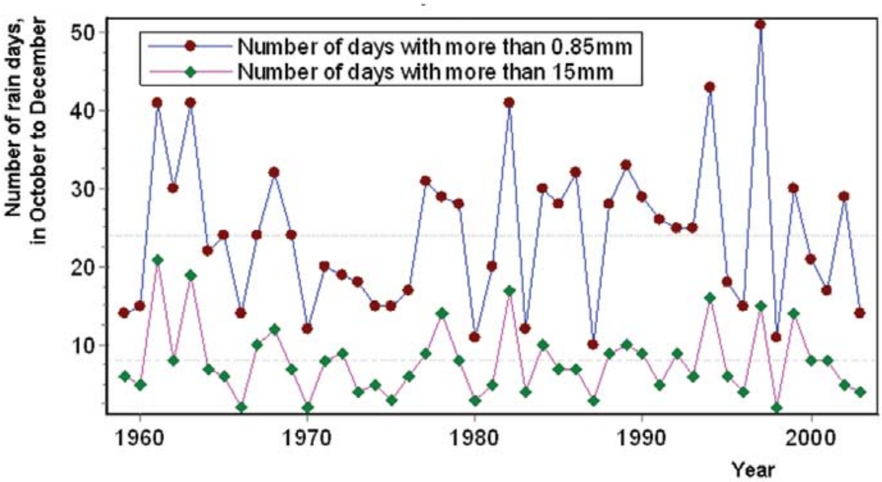


Figure 15. The number of days per the short rainy season at Makindu (October, November, December) when (i) rainfall >0.85 mm was recorded and when (ii) >15 mm was recorded.

This analysis, perhaps more than any other, indicates the great uncertainty associated with rainfed farming, especially in semi-arid tropical environments such as Makindu. 'Planting dates' are hugely variable (ranging from mid-October to the end of December), and furthermore in 18% (8 out of 45) of the seasons, planting on the dates identified would have been followed by a 12-day dry spell which would have probably killed germinating seeds and necessitated re-planting.

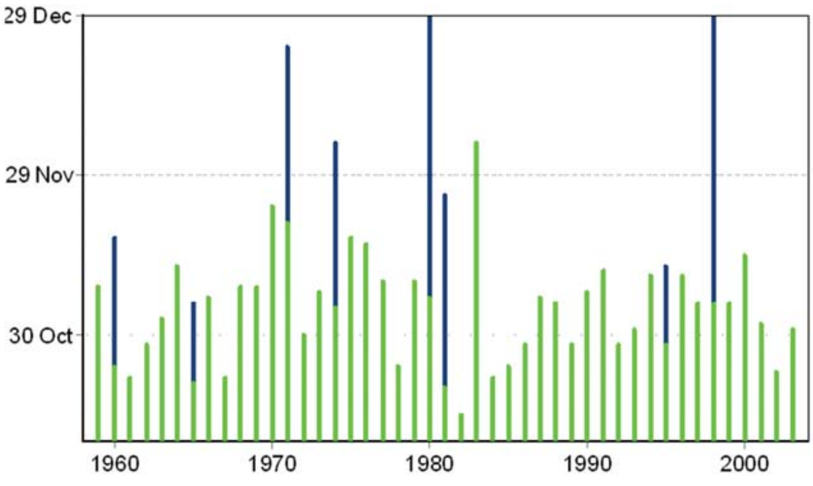


Figure 16. The date of onset of the short rainy season at Makindu, Kenya under two scenarios: (A) the date by which 15 mm fell in a 3-day period (green line) and (B) Scenario 'A', but with the caveat that it should not be followed by a 12-day dry spell (blue line).

We would like to finalize this example by asking the question: 'If farmers near Makindu had planted on the date identified in Figure 16, what would have been the probability of that particular crop experiencing a damaging dry spell during the sensitive flowering/seed set period?' We assumed no particular crop, but examined the implications for crops of different growth duration which flowered and set seeds in a 20-day period that spanned: (a) 30–50 days and (b) 45–65 days post planting. The results of that analysis are presented in Figure 17.

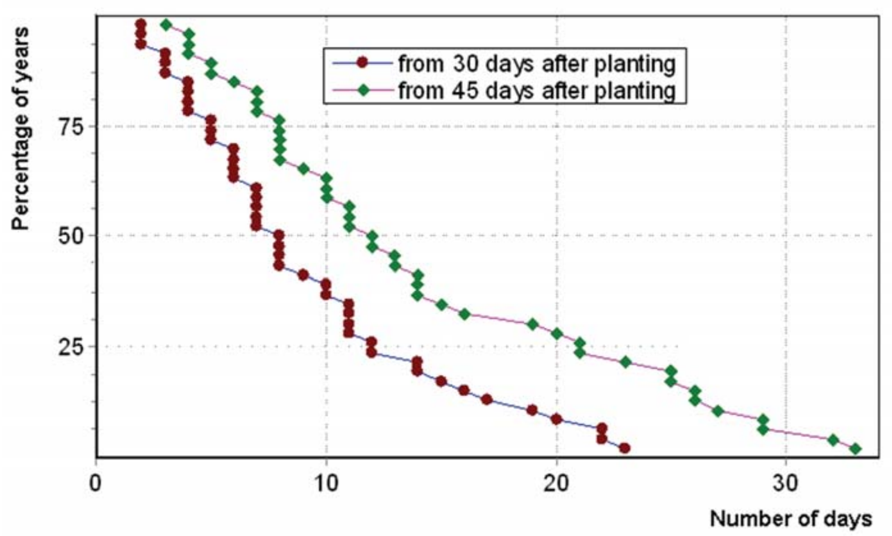


Figure 17. The percentage chance of exceeding contrasting durations of dry spells between 30–50 and 45–65 days post-planting during the short rainy season at Makindu, Kenya.

Dry spells during flowering are clearly a real risk at Makindu, but it is also clear that shorter duration crops will be exposed to lower risks. For example, there is about a 60% chance of a 10-day dry spell over the flowering period with the longer duration crop (green points) compared to about a 30% chance with the shorter duration crop (brown points). In either case though, the risks are high.

In conclusion to this section, we wish to repeat that the 'rules' that we used to illustrate the value of this kind of analyses, whilst not arbitrary, where rules that we chose. Users of GenStat and INSTAT software can choose whatever set of rules that they feel are most appropriate for the situation that they wish to investigate.

Length of growing period: Current and future climate-induced risk at Makindu

The length of growing period (LGP) at any location is an important indicator of the yield potential of that location and determines the suitability of contrasting management practices and maturity length crop types and cultivars. The LGP is defined as the number of days in any given rainfall season when there is sufficient water stored in the soil profile to support crop growth. It can be calculated from knowledge of incoming daily rainfall, daily soil evaporative and crop transpiration demand and the ability of the soil to store water within the crop rooting zone. From the previous paragraphs, using Makindu in Kenya as an example, we have seen the natural season-to-season variability in rainfall amounts and distribution as well as temperature fluctuations. Such variability will inevitably be reflected in season-to-season variability in LGP.

Cooper et al. (2009) used the crop/water balance routine of APSIM and determined LGP for the same 45 short rainy seasons at Makindu (1959–2004). They simulated three scenarios. Firstly, they investigated the range of LGPs under the current climatic conditions (control). Secondly they assessed the impact of a 3°C increase in mean temperature (a worst case scenario for 2050) but retained rainfall levels at their present day values and distributions. Thirdly, given that APSIM is well able to simulate the impacts of water conservation innovations (Okwach and Simiyu, 1999), they investigated to what extent mulching with maize crop residues could mitigate the possible negative impacts of increased temperature on the LGP. The outputs of these analyses for the 45 seasons are presented in Figure 18 in a probability format as the ‘% chance of exceeding’ any given LGP.

The implications of the outputs of this analysis are important from two perspectives. Firstly, even under the current climate, farmers in Makindu experience LGPs ranging from 25 days (crop failure) to over 175 days as shown by the blue ‘control’ line in Figure 18. A 5–10% decrease in the average LGP due to global warming (as suggested by the analyses of Thornton et al., 2006) therefore is unlikely to result in farmers having to cope in the future with a situation that they have not and are not already experiencing.

Secondly, the average LGP at Makindu under current climate and current soil management is 110 days, but this is reduced by 8%, with a 3°C rise in temperature, to 101 days. However, the application of maize residue mulch under the climate change scenario in fact raised the average LGP to 113 days, 3 days longer than under current climate conditions. When the mulch was applied, only in the 30% of the most favourable seasons was the LGP, under a 3°C temperature increase, lower than that experienced today.

In summary, not only can water conservation measures have important beneficial impacts on water storage in the soil profile and hence the LGP under current climate conditions, they can also play a major role in helping to manage and ameliorate the impact of future climate change on the LGP.

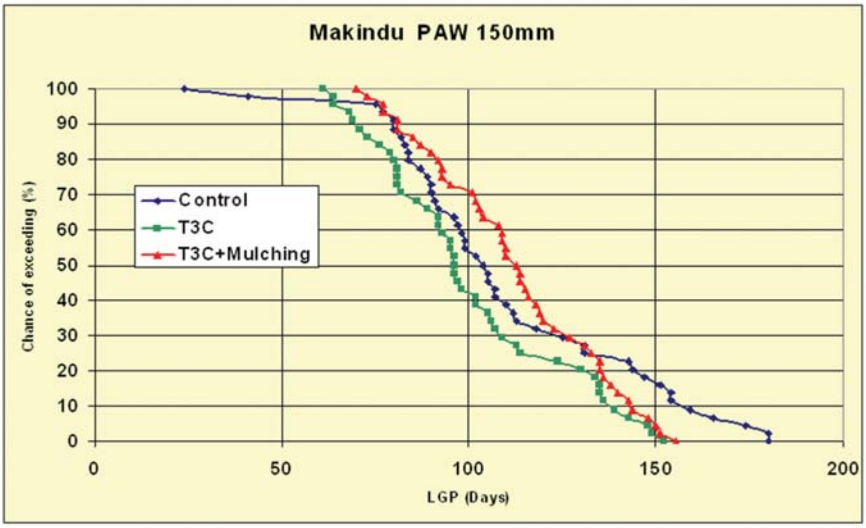


Figure 18. The simulated (APSIM) probability distribution the LGP during the short rains (October, November, December) at Makindu, Kenya (1959 to 2004) under (i) current practice of no water conservation (control), (ii) an increase of 3°C, and (iii) and increase of 3°C with a mulch for maize of crop residues.

Water conservation practices, maize yields and climate-induced risk at Makindu

In many parts of the semi-arid tropics, including Makindu, intense rainfall events result in frequent surface water runoff and soil erosion (see also Figure 15). Under such conditions, water conservation innovations are recommended in order to reduce such runoff losses and increase the amount of water that is stored in the soil profile for subsequent crop use and an anticipated increase in grain yield. How often in a 10 year span will such innovation pay off for farmers?

Cooper et al. (2009) used APSIM to examine the climate induced risk associated with water conservation innovations under current climatic conditions at Makindu. In the examples that we give here, APSIM was programmed to simulate the impact of two water conservation innovations on surface water runoff, namely (i) soil ridging on the contour; and (ii) soil mulching with maize residues under both unfertilized and fully N-fertilized maize at Makindu and hence their impact on maize yield. The output provided simulations of what the impact of these measures on maize yield would have been for each of the short rainy seasons between 1959 and 2004. These 45 sets of results were then plotted in a probability format as the per cent chance of exceeding any given maize yield and are presented in Figure 19 and Figure 20.

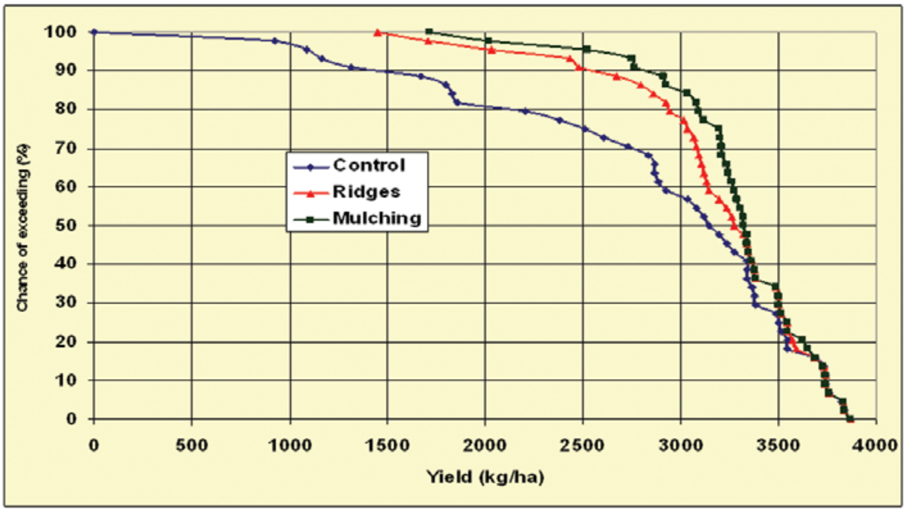


Figure 19. The simulated (APSIM) probability distribution of nitrogen non-limited maize yields during the short rains (October, November, December) at Makindu, Kenya (1959 to 2004) under (i) current practice of no water conservation (control), (ii) contour ridging and (iii) mulching with a maize crop residue.

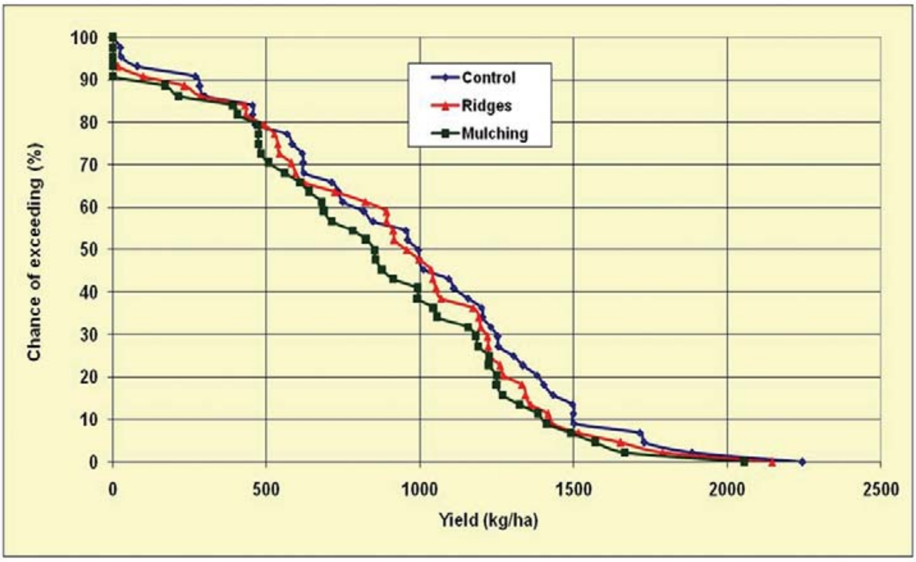


Figure 20. The simulated (APSIM) probability distribution of unfertilized maize during the short rains (October, November, December) at Makindu, Kenya (1959 to 2004) under (i) current practice of no water conservation (control), (ii) contour ridging and (iii) mulching with a maize crop residue.

The outputs of these simulations clearly illustrate the impact of season-to-season rainfall variability on the risk associated with maize yield production in dry environments such as Makindu where, across all scenarios, yields ranged from 0 to 2000 kg/ha and 0 to nearly 4000 kg/ha under unfertilized and nitrogen (N)-fertilized maize respectively. They also illustrate the very contrasting impacts of water conservation innovations in the presence and absence of N fertilizer inputs.

In the absence of any N-fertilizer input (Figure 20) the impact of water conservation innovations on maize yield was largely insignificant or negative resulting from increased leaching of already low levels of nitrate beyond the crop rooting zone. In contrast to this, under fully N-fertilized maize, much more positive yield responses to water conservation were obtained (Figure 19). However, the benefit of such practices is really only evident in the 50% least favourable (driest) seasons. In the more favourable seasons of higher rainfall, farmers would appear to be unlikely to obtain satisfactory rates of return to their labour investments for ridging or the lost opportunity of utilizing maize crop residues as an animal fodder. This type of climate-induced risk analyses can clearly add great value to more field based research and suggests very probable reasons why current adoption of such innovations remains low.

A example from Zimbabwe of risk assessment and management using APSIM

In southern semi-arid Zimbabwe N deficiency is widespread in maize and yields are low and variable. N fertilizer use is recommended at a rate of 52 kg/ha, but is seldom adopted by farmers. It is considered too risky and expensive. Researchers therefore asked farmers how much fertilizer they could afford and would actually be prepared to use under such conditions and were told about 17 kg N/ha, one-third of the recommended rate. A total of 50 years of daily climatic data from Masvingo (1951–2001) were used to simulate maize yields with 0, 17 and 52 kg N/ha. The results of this simulation confirmed farmers' perception of variable N-response, but also suggested useful responses to 17 kg N/ha. (Figure 21). The outputs of this simulation were then calculated as 'economic rates of return' to fertilizer use and expressed in terms of the per cent chance of exceeding any given rate of return to N-fertilizer use (Figure 22). Except in very bad years, rates of return at the farmer preferred rate of 17 kg N/ha were substantially better than at the recommended rate. In addition, the simulated rates of return at the low rate of N-fertilizer use exceeded farmers' required value of 5:1 in over 8 years out of 10.

These simulated results were discussed with farmers and gave them, as well as fertilizer traders and extension staff, for the first time, a quantification of the climate-induced risk associated with fertilizer use. As a result, it gave them the confidence to successfully evaluate this 'micro-dosing' rate of N with 170,000 farmers in Zimbabwe in the 2003/04 cropping season alone. The initiative is ongoing. It is enabling farmers to adapt their attitude toward and their practice of fertilizer use, their support agents to adapt their fertilizer recommendations and fertilizer manufacturers to adapt their marketing approach (ICRISAT, 2008).

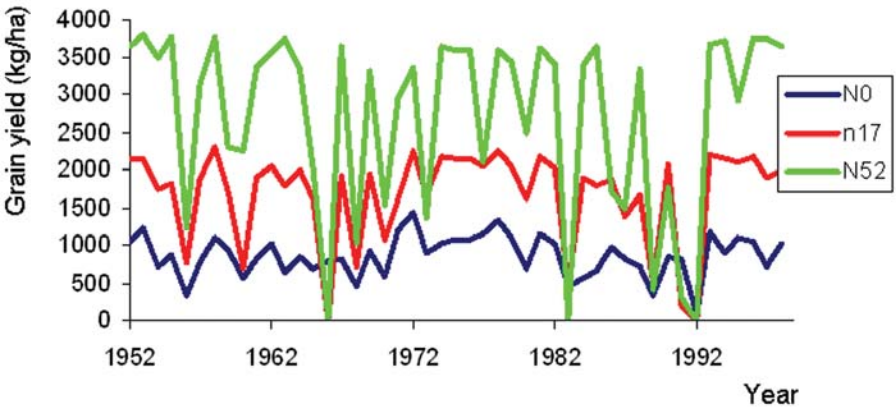


Figure 21. The simulated (APSIM) distribution of maize grain yields receiving 0, 17 and 52 kg/ha N using climate data (1951–2001) from Masvingo, Zimbabwe.

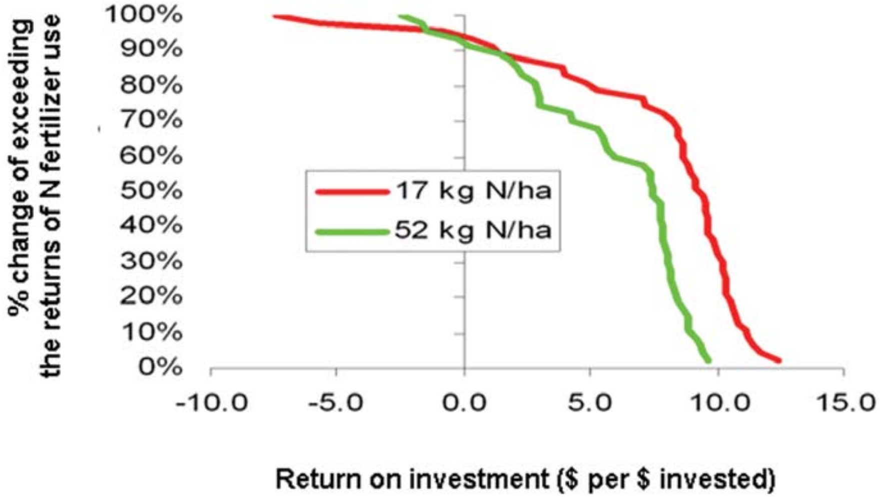


Figure 22. The simulated (APSIM) distribution of the per cent chance of exceeding the returns of N-fertilizer use from Masvingo, Zimbabwe.

Impact of increased drought frequency on livestock assets of pastoralists

Pastoralists live in regions where the current season-to-season variability in rainfall is great and impacts of climate change are likely to be large (Thornton et al., 2006) These areas include the Sahelian rangelands, southern Africa, and parts of East Africa. Livestock keepers in these regions are among the most vulnerable on the planet. They rely on livestock as their primary form of living. Livestock provides a number of benefits to pastoral families in the form of milk, meat, hides, manure and others. Livestock also represent a considerable asset that can be traded or sold during difficult times or for purposes such as paying school fees or providing dowry

(Nkedianye et al., 2009). The impact of drought on herd performance and asset values has been widely documented. In large areas of Africa where pastoralism dominates, frequent droughts can decimate herds and displace pastoralists. Drought frequencies of one in four or five years are not uncommon under current climatic conditions (Orindi et al., 2007). As a result, emergency services and humanitarian relief efforts are often needed to support pastoralist families during considerable parts of the year in these regions.

Thornton and Herrero (2009) ran a herd dynamics model to investigate the potential impacts of increased drought frequency, possibly associated with future climate change, on herd dynamics and livestock numbers. The model of Lesnoff (2007) was used and was parameterized with the data of Boone et al. (2005). Data on the mortality, reproduction and herd structures from pastoralist herds in Kajiado, Kenya, were used as baseline information.

The model was run over 20 years assuming a herd baseline size of 200 animals, of which 60 where adult females. Two scenarios were examined: a baseline scenario simulating a situation that realistically reflects current climatic conditions, namely one drought every five years, and an alternative scenario of increased frequency of droughts—one year in three. Such increases in drought frequency may be anticipated as a result of global warming although details are far from clear (IPCC, 2007b). In years of drought, animal mortality rates increase and reproductive performance of adult females declines, potentially resulting in lower numbers of offspring and declining herd size.

Results indicate that a drought once every five years (i.e. representative of current conditions) keeps herd sizes stable (Figure 23), and this has been observed in Kajiado for a long time (Rutten, 1992). At the same time, the district has seen substantial increases in human population, meaning that the proportion of the population that can thrive in a pastoral setting has plummeted because animal numbers per adult equivalent are simply not sufficiently high to support pastoralism. This might reflect that the ecosystem simply cannot support more animals (except at the possible expense of wildlife, with other income-related effects).

When the probability of drought was increased to once every three years, herd sizes decreased as a result of increased mortality and poorer reproductive performance (see Figure 23). This decrease in livestock numbers would affect food security and would compromise the sole dependence of pastoralists on animals and their products, as well as the additional benefits they confer. This simple analysis shows that under increased climate variability, the need for diversification of income, a strategy often (and increasingly) observed in pastoral areas, becomes ever more important. Climate change and increased frequency of droughts will have substantial impacts on environmental security. In addition, conflicts (usually over livestock assets) often observed in these regions are likely to escalate in the future (Bocchi et al., 2006).

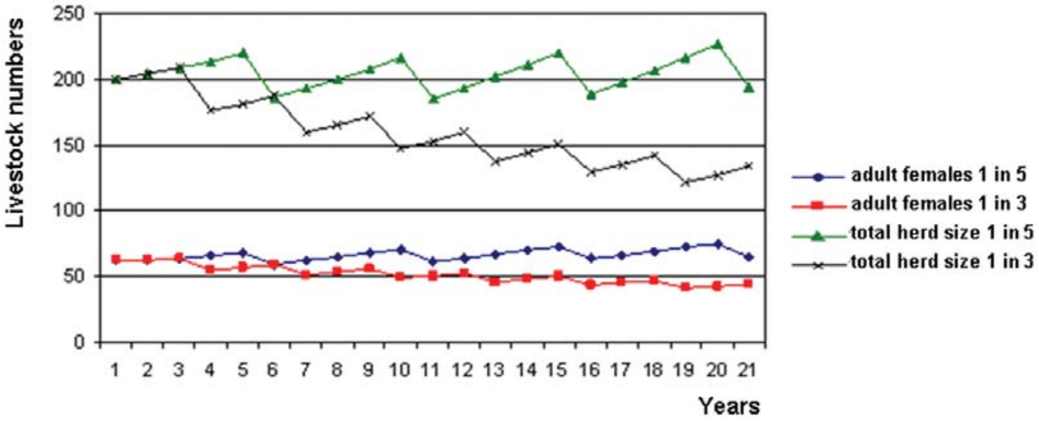


Figure 23. Evolution of total herd size and the number of adult females under two scenarios of drought frequency: (i) a drought once every five years, and (ii) a drought once every three years.

Key messages

- The rainfed agricultural sector in ECA has stagnated over recent decades.
- Market and policy failures have played an important and negative role, but climate induced risk in rainfed agriculture remains a fundamental constraint to adoption of improved production practices for small-scale and risk averse farmers.
- Although many profitable agricultural innovations have been identified and promoted, widespread adoption remains low.
- All such innovations will be affected to a greater or lesser extent by the season-to-season rainfall variability that is characteristic of current climates.
- The promotion of such innovations is seldom supported by climate-induced risk information which addresses the key question ‘in how many years out of 10 will such an innovation provide rates of return that are acceptable to risk-averse farmers?’
- A range of easily available and user-friendly tools are accessible that allow the quantification of climate-induced risk in rainfed agriculture and also allow the ex ante assessment of climate change scenarios. Examples of how such tools can be used to quantify climate induced risk are provided.

6. Implications of climate change on agriculture and pastoralists in the ASARECA region

The consequences of climate change are potentially more significant for the poor in developing countries than for those living in more prosperous nations. Vulnerability to the impacts of climate change is a function of exposure to climate variables, sensitivity to those variables, and the adaptive capacity of the affected community. Often, the poor are dependent on economic activities that are sensitive to the climate. For example, agriculture and forestry activities depend on local weather and climate conditions; a change in those conditions could directly affect productivity levels and diminish livelihoods (USAID, 2007).

Climate change can cause abrupt disruptions in climate events, such as floods, droughts or tropical storms. These disruptions can take a major toll on a country's economy if a significant part of the economic activity is sensitive to the weather and climate. Ethiopia provides a good example of the influence of rainfall variability on a developing country's economy.

Figure 24 shows that GDP in Ethiopia rises or falls about a year after changes in seasonal average rainfall across the whole country. With agriculture accounting for half the GDP and 80% of the jobs, the Ethiopian economy is sensitive to variations in rainfall. Small countries with GDP concentrated in a few climate-sensitive sectors, like agriculture, can see substantial portions of their land area and economic sectors affected by extreme weather events and disasters (USAID, 2007).

This chapter explores the implications of climate change on the agricultural sector.

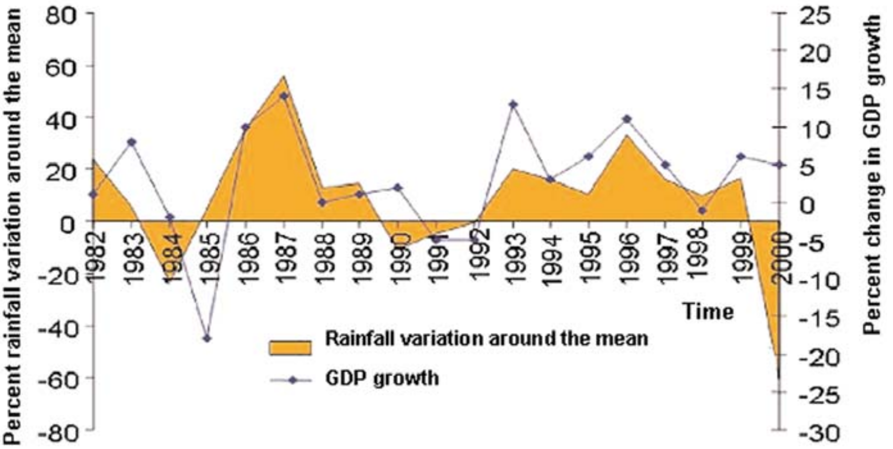


Figure 24. Trends in gross domestic product (GDP) and rainfall in Ethiopia (World Bank, 2006).

6.1. Where are the impacts?

The combination of higher evapotranspiration and even a small decrease in precipitation could lead to significantly greater drought risks. An increase in precipitation variability would compound temperature effects (Sivakumar et al., 2005). Like Fischer et al. (2002) and Jones and Thornton (2003), in this report we assess the impact of climate change on agro-ecological characteristics by looking at changes in LGP. Changes in rainfall patterns, in addition to shifts in thermal regimes, influence local seasonal and annual water balances and in turn affect the distribution of periods during which temperature and moisture conditions permit agricultural crop production. Such characteristics are well reflected by the LGP since most countries of ECA rely on rainfed agriculture (Fischer et al., 2002; Comprehensive Assessment, 2007).

LGP was calculated as described by Thornton et al. (2006). In this study, for each 10-minute pixel in Africa climate normals data, monthly values for average daily temperature (°C), average daily diurnal temperature variation (°C), and average monthly rainfall (mm), were read from the appropriate gridded file and interpolated to daily data using the method of Jones (1987). Potential evapotranspiration was calculated according to Linacre (1977). The water balance was calculated using WATBAL (Yates, 1996) which uses the method of Keig and McAlpine (1974). It calculates the available soil water, runoff, water deficiency and the actual to potential evapotranspiration ratio (Ea/Et), using a simplified version of Reddy (1979). Ea/Et is calculated from a square root function that fits the three points supplied by Reddy (1979) depending on soil water holding capacity. A moderate soil water holding capacity of 100 mm is assumed for all soils. While running the water balance simulation, the number of days with Ea/Et greater than 0.5 were counted as potential growing days from day-of-year 1 to day-of-year 365. A further restriction was placed to eliminate cold highland areas. Days with average temperature less than 9°C were not counted as growing days even if water was not limiting. The information in Figure 25 shows the projected LGP. By applying this method, LGP is actually the total number of days in a year when there is enough water to support crop growth. It does not include bimodal rainfall regimes when the two seasons are actually interspersed with a dry period which would kill any crop.

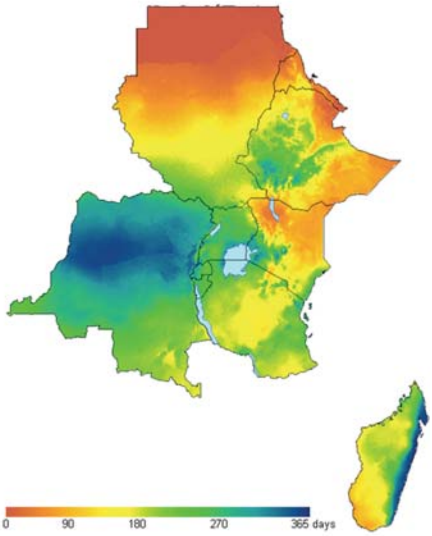


Figure 25. Length of growing period (days per year) for current conditions (2000) for ASARECA countries.

Seré and Steinfeld (1996) define arid regions as having LGP of less than 75 days, semi-arid regions as having LGP in the range 75–180 days, subhumid regions as having LGP in the range 181–270 days, and humid regions as having LGP greater than 270 days.

Changes in LGP

Thornton et al. (2006) presents LGP changes for Africa to 2050 under various model projections, showing few differences in projections under two SRES scenarios (A1F1 and B1). The 'A' scenarios place more emphasis on economic growth, the 'B' scenarios on environmental protection. The '1' scenarios assume more globalization. For this report revised spatial data layers are utilized (Thornton and Jones, 2008). LGP changes to 2030 and 2050 are projected for Africa using downscaled outputs of coarse-gridded GCM, using methods outlined in Jones and Thornton (2003), using the data sets of WorldCLIM (Hijmans et al., 2005), TYN SC 2.0 data set (Mitchell et al., 2004), and the outputs from the Hadley Centre Coupled Model version 3 (HadCM3) (Mitchell et al., 1998) and ECHam4 (Roeckner et al., 1996), associated with A1FI and B1 (IPCC, 2001).

Figure 26 shows maps of projected changes in LGP from 2000 to 2030 and 2050, from downscaled outputs of the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1. Following IPCC (2001) map legends, these changes were classified into five: losses in LGP of >20% ('large' losses); of 5–20% ('moderate' losses); no change (± 5% change); gains of 5–20% ('moderate' gains); and gains of >20% ('large' gains).

Similar to Thornton et al. (2006) various points can be made about these maps. First, some of the large losses and large gains are located in areas with LGP less than 60 days, i.e. in highly marginal areas for cropping but important for pastoralists. This implies that pastoralism will continue to be a significant livelihood option in these regions vis-à-vis crop expansion in marginal lands under current circumstances. Second, there is considerable variability in results arising from the different scenarios, and there is also variability in results arising from the different GCMs used. Third, if anything could be generalized about these different maps, it is that under the range of these SRES scenarios and the GCMs used, many parts of ECA are likely to experience a decrease in LGP, and in some areas, the decreases may be severe. This means that projected increases in temperature and projected changes in rainfall patterns and amount (increases in rainfall amounts are projected in many areas) combine to suggest that growing periods will decrease in many places. There are also a few areas where the combination of increased temperatures and rainfall changes may lead to an extension of the growing season; these appear to occur in some of the highland areas of Kenya and Ethiopia.

The results in Table 3 present the distribution of the surface area of the countries over certain LGP classes for the years 2000, 2030 and 2050. These results are averages of the pixels for the different classes of LGP based on of the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

Table 3. Average distribution and range (minimum and maximum) of surface area (%) of individual countries under different classes of lengths of growing periods for the years 2000, 2030 and 2050, based on averages of the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1

	Length of growing period (days)													
2000 (%)	**< 90**		**90–120**		**120–150**		**150–180**		**180–210**		**210–250**		**>250**	
Burundi	0		0		0		0		7		76		17	
DRC	0		0		0		5		13		12		71	
Eritrea	79		14		5		1		0		0		0	
Ethiopia	31		15		13		15		13		9		4	
Kenya	44		16		12		8		6		7		8	
Madagascar	6		11		14		32		11		7		18	
Rwanda	0		0		0		0		9		40		52	
Sudan	61		10		11		11		4		2		0	
Tanzania	0		2		18		39		24		12		4	
Uganda	0		0		1		5		12		44		39	
2030* (%)														
Burundi	0		0		0		0		12		74		14	
DRC	0		0		1		10		11		17		61	
Eritrea	90		8		2		0		0		0		0	
Ethiopia	31		16		12		15		13		9		4	
Kenya	44		15		15		8		6		6		7	
Madagascar	10		14		30		20		7		5		14	
Rwanda	0		0		0		0		21		34		44	
Sudan	63		11		11		11		5		0		0	
Tanzania	0		4		28		36		21		7		3	
Uganda	0		0		0		4		17		40		39	
2050 (%)														
Burundi	0		0		0		3	0–7	29	20–41	57	43–68	11	9–12
DRC	0		0		2	1–3	14	11–17	14	11–18	18	17–20	52	45–59
Eritrea	93	89–97	7	3–10	1	0–2	0		0		0		0	
Ethiopia	33	29–37	15	13–17	13	11–14	15	14–15	12	11–13	8	7–11	3	3–4
Kenya	45	43–47	15	13–17	15	13–17	7	7–9	6	6–6	5	4–6	6	5–7
Madagascar	13	10–15	17	11–25	29	21–34	17	11–24	6	5–7	5	4–6	13	11–15
Rwanda	0	0	0		0		3	0–13	34	29–37	29	28–30	34	28–38
Sudan	64	62–65	11	11–12	11	11–12	10	9–11	3	3–5	0	0–1	0	
Tanzania	0		7	6–9	32	28–37	36	35–38	18	12–23	5	4–6	3	2–3
Uganda	0		0	0	1	0-3	9	4–15	27	23–32	40	35–45	23	14–31

* Note that for 2030 there is no difference in projections for the distribution of surface area over the length of growing period classes between the different models and scenarios.

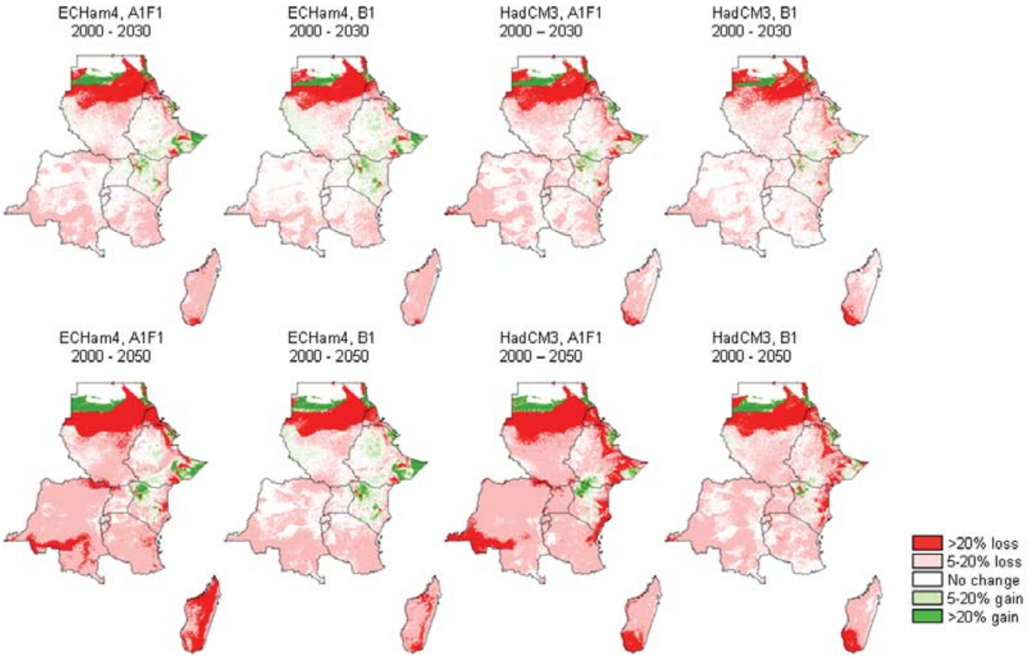


Figure 26. Percentage change in LGP to 2030 (upper row) and 2050 (lower row), for different models and scenarios (Adapted from Thornton et al., 2006).

Many parts of ECA are likely to experience a decrease in LGP (Table 3). This is in agreement with Herrero et al. (2008) who showed increases in arid pastoral and mixed systems in Africa at the expense of humid and temperate areas. The surface area with a short growing period (less than 90 days) will increase, especially in Madagascar and Sudan. The surface area with a prolonged growing period (more than 210 days) will decrease in most countries. There are no differences in projections for the distribution of surface area over the LGP classes between the different models and scenarios to 2030. After 2030 the range of change between the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1 increases.

6.2. Which production systems and commodities are mostly affected?

In order to determine which agricultural production systems are likely to be most affected by climate change, spatial data layers with percentage changes in LGP to 2030 and 2050, for the ECHam4 and the HadCM3 GCM and scenarios A1F1 and B1, were overlaid with a relatively coarse agricultural systems classification. Since ASARECA research activities follow a sustainable livelihoods approach (i.e. in recognition of some of the strategies that are being used by households in particular places, related to uses of natural resources), an agricultural system classification was employed in this study.

Seré and Steinfeld (1996) developed a global livestock production system classification scheme. The system breakdown has four production categories: landless systems (typically found in peri-urban settings), livestock/rangeland-based systems (areas with minimal cropping, often corresponding to pastoral systems), mixed rainfed systems (mostly rainfed cropping combined with livestock, i.e. agropastoral systems), and mixed irrigated systems (significant proportion of cropping uses irrigation and is interspersed with livestock). All but the landless systems are further disaggregated by agro-ecological potential as defined by LGP: arid–semi-arid (with LGP <180 days), humid–subhumid (LGP >180 days), and tropical highlands/temperate regions. A method was devised for mapping the classification by Kruska et al. (2003), and is now regularly updated with new datasets (Kruska, 2006). This method was recently revised by Thornton et al. (2006) (Figure 27). The classification was mapped using various data sets: for land-use/cover, the Global Land Cover (GLC) 2000 data layer, version 3 (JRL, 2005); for human population, the GRUMP 1-km data (CIESIN et al., 2004); for LGP, the WorldCLIM 1-km data for 2000 (Hijmans et al., 2005), together with a new 'highlands' layer for the same year based on the same data set (Jones and Thornton, 2005).

In ECA the arid–semi-arid systems are found in Sudan, northern Uganda and the lowlands of Kenya and Ethiopia. The humid–subhumid systems are typical in DRC and Uganda, while the intensive dairy systems in the highlands of Kenya and Ethiopia are typical for the tropical highlands/ temperate systems.

The first three yellowish colours represent the livestock based farming systems, the purple colours the mixed irrigated and the blue colours the mixed rainfed.

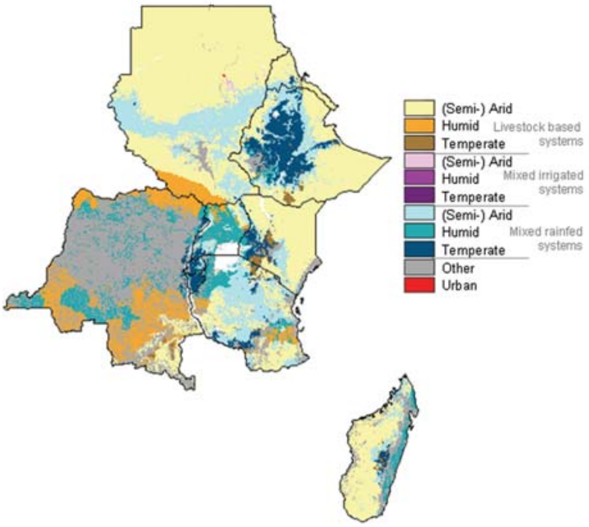
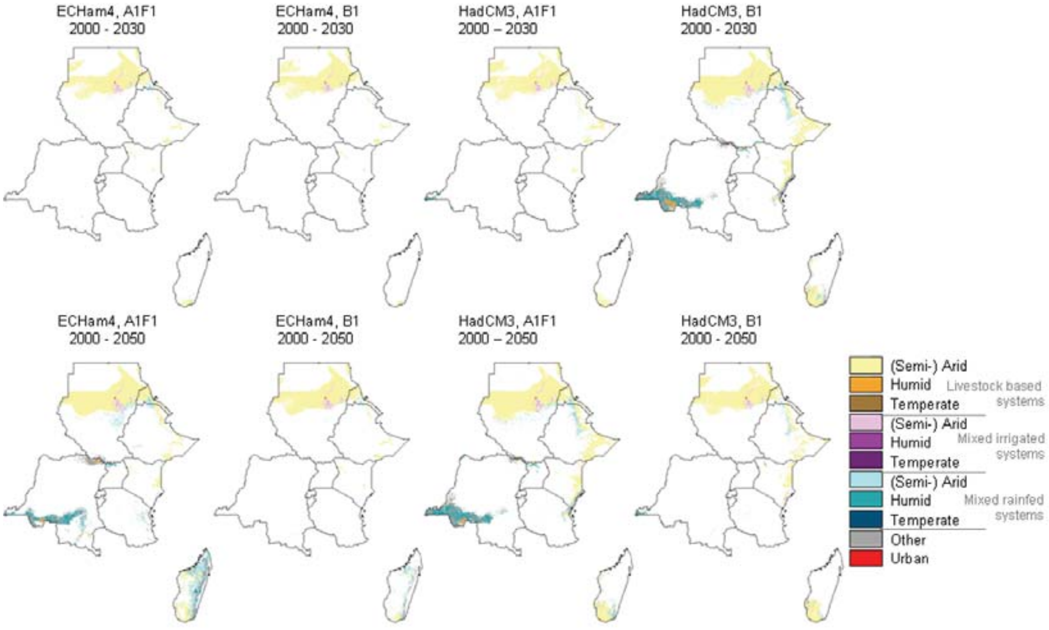


Figure 27. Farming systems classification for ASARECA countries (Adapted from Thornton et al., 2006).

To look at possible changes in the future, the Global Rural–Urban Mapping Project (GRUMP) human population data and projected population out to 2030 and 2050 by pro rata allocation of appropriate population figures (the United Nations (UN) medium-variant population data for each year by country) were used (Herrero et al., 2008). LGP changes to 2030 and 2050 are projected using downscaled outputs of coarse-gridded GCMs, using methods outlined in Jones and Thornton (2003) and the data set TYN SC 2.0 (Mitchell et al., 2004) and the outputs from the Hadley Centre Coupled Model version 3, HadCM3 (Mitchell et al., 1998), associated with the emissions scenario A1F1 (IPCC, 2001).

In Figure 28 farming systems in areas with losses in LGP of >20% for 2030 and 2050 under various model projections are presented, showing slight differences in projections under A1F1 and B1 scenarios. The results of overlaying LGP change classes with the agricultural systems classification layer are tabulated in Appendix B. To summarize the data, categories were assigned using the five classes of the percentage change in LGP: changes in LGP with >20% losses; of 5–20% losses; no change (± 5% change); of 5–20% gains; and of >20% gains. Appendix B shows the area of the different farming systems classes for 2000, 2030 and 2050. It also shows the minimum and maximum averages of the pixels for the different classes of LGPs between the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

From Figure 28 it is clear that especially the livestock based systems will be affected by large losses in LGP, as these systems are predominant in the marginal areas that are expected to experience a decrease in growing days. Appendix B shows that in Sudan, depending on the model and scenario, 29% to 35% of the surface area of the livestock based systems in the semi-arid regions is expected to experience a decrease in areas. In Uganda moderate losses of 2% to 19% of the surface area in the semi-arid mixed rainfed systems and 4% to 35% of the surface area in the humid mixed rainfed systems are expected.



The first thee yellowish colours represent the livestock based farming systems, the purple colours the mixed irrigated and the blue colours the mixed rainfed.

Figure 28. Farming systems in areas with losses in LGP of more than 20% for 2030 (top) and 2050 (bottom) for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1 (Adapted from Thornton et al., 2006).

Value of production

The relative importance of the different agricultural commodities varies by country and production system. To assess the relative importance of agricultural commodities, the value of agricultural production of agricultural products was determined. Alongside other types of information, a better understanding of the value of production (and therefore importance) of agricultural commodities could help target investments, both in terms of commodities and regions (Freeman et al., 2008). The value of production (VOP) was calculated using the formula:

$$\text{VOP } i = (\text{Prod } i * \text{Price } i)$$

where: VOP *i* is value of production for commodity *i* (US$), PROD *i* is production of commodity *i* (MT), and PRICE *i* is price of commodity *i* (US$/MT).

The production data and prices were derived from the FAO statistical database (FAOSTAT) for 2004 to 2006. An average value for these years was used to reduce outliers and large annual fluctuations. This period was chosen as other data sources, like the farming systems map and LGP data are also for this period. For some commodities no price data were available for some countries; for these countries average regional prices were used. The results in Table 4 present the total VOP (×1000 US$) of different commodities for ECA, and the relative contribution of countries. Some results per country are given in Table 7 to Table 16. The data in the following section show the relative economic importance of commodities for a country; no projections over time or price fluctuations are given. The data in the tables are intended to be used to assess the magnitude of the impact of climate change, using the value of the crop as in indicator. This is a broad brush analysis, based on country-level production estimates and prices. The results should therefore be used with the necessary caution (Freeman et al., 2008).

Table 4. The total value of production (in 1000 US $) of different commodities for East and Central Africa, and the relative contribution of countries

Commodity	Burundi (%)	Congo (%)	Eritrea (%)	Ethiopia (%)	Kenya (%)	Mada-gascar (%)	Rwanda (%)	Sudan (%)	Tanzania (%)	Uganda (%)	Total VOP (1000 US $)
Crops											
Cassava	2.4	52.2	0.0	0.0	0.8	3.3	1.7	0.1	23.1	16.5	6,990,341
Maize	1.3	13.6	0.1	14.2	20.4	1.0	0.6	1.3	34.7	12.7	2,208,327
Sweet potatoes	10.5	4.1	0.0	1.1	17.3	5.3	6.7	0.3	13.4	41.4	1,031,319
Sorghum	2.3	0.1	3.4	18.2	2.2	0.0	3.7	48.1	13.7	8.3	944,015
Rice	1.7	12.3	0.0	0.3	1.6	53.7	0.8	0.4	25.2	3.9	844,449
Banana plantain	63.0	7.4	0.0	0.9	5.1	2.3	0.0	3.5	3.5	14.3	810,833
Potatoes	0.9	3.0	2.1	4.0	38.6	3.7	10.2	13.1	8.3	16.1	804,825
Bean	13.8	7.2	0.2	3.9	18.1	4.6	6.6	3.7	15.5	26.3	786,313
Coffee	4.7	6.5	0.0	28.2	17.5	4.5	1.6	0.0	7.6	29.5	732,889
Sugar cane	1.5	10.1	0.0	14.4	14.4	26.6	0.2	15.3	8.5	9.1	705,392
Groundnut	1.1	33.8	0.2	0.4	4.6	1.5	0.8	39.9	5.3	12.5	593,592
Tea	0.0	0.0	0.0	0.7	87.5	0.0	6.3	0.0	0.0	5.5	538,659
Millet	0.3	1.9	1.1	9.3	3.5	0.0	0.2	37.8	12.2	33.8	485,035
Wheat	0.4	0.6	1.7	62.2	13.0	0.4	0.5	14.8	5.5	0.8	400,744
Cotton	0.4	4.2	0.0	3.8	1.8	6.9	0.0	48.6	26.3	8.1	197,054
Barley	0.0	0.1	5.3	84.6	9.4	0.0	0.0	0.0	0.6	0.0	180,930
Soybean	0.4	6.9	0.0	7.5	0.0	0.0	10.1	0.0	1.3	73.8	53,571
Meat											
Cattle	1.5	1.2	1.9	10.1	22.1	7.0	1.7	25.5	20.2	8.9	1,640,774
Sheep	0.4	1.0	4.4	5.7	6.3	0.5	0.2	76.0	3.7	1.9	455,955
Poultry	3.1	4.3	0.9	8.9	23.8	21.1	0.9	4.6	16.2	16.3	441,101
Goats	1.9	8.5	5.2	6.9	15.5	1.6	0.8	35.5	13.2	11.0	342,379
Pigs	4.8	13.3	0.0	0.1	6.1	28.7	1.1	0.0	6.4	39.6	306,006
Camel	0.0	0.0	3.5	3.1	16.5	0.0	0.0	76.8	0.0	0.0	70,959
Milk											
Cattle	0.9	0.1	1.3	21.6	28.7	8.7	4.9	0.0	19.9	13.8	1,523,807
Goat	0.2	0.0	0.5	0.8	4.6	0.0	1.5	86.9	5.5	0.0	654,330
Sheep	0.0	0.0	0.5	2.5	2.1	0.0	0.3	94.5	0.0	0.0	298,652
Camel	0.0	0.0	5.8	0.0	31.3	0.0	0.0	62.9	0.0	0.0	25,669
Eggs	3.3	4.0	1.5	7.1	20.1	3.8	1.7	27.1	19.8	11.6	304,270

Impacts on crops

The LGP change classes for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1 were also overlaid with crop layers for ECA. You and Wood (2004) completed the spatial allocation of the main crops grown worldwide. The pixel-scale allocations were performed through the compilation and fusion of relevant spatially explicit data, including production statistics, land use data, satellite imagery, biophysical crop 'suitability' assessments, population density, and distance to urban centres, as well as any prior knowledge about the spatial distribution of individual crops (You et al., 2007). The resulting data set comprises global estimates of area, production and yields of rice, wheat, maize, sorghum, millet, barley, groundnuts, cowpeas, soybeans, beans, cassava, potato, sweet potato, coffee, sugar cane, cotton, bananas, cocoa, and oil palm at a resolution of 5 minutes. Unfortunately, the data set provides no information on all crops that are important in the region, like tea and teff.

The results of overlaying LGP change classes with the crop layers are tabulated in Appendix C. To summarize the data, categories were assigned, using the five classes of the percentage change in LGP. The table in Appendix C shows the differences in results between the GCMs and scenarios by presenting the minimum and maximum value in relative distribution of the crop layers. The total surface area of crop per country for 2000 is also presented. In contrast to farming systems, for the crop layers no projections for 2030 and 2050 are used, meaning that the current crop distributions are used to assess which crops are possibly affected by climate change. Please notice that these are broad brush analyses, based on country-level production estimates. The results should therefore be used with the necessary caution. These tables are presented as indicative of what kinds of crops are currently most vulnerable to the possible effects of climate change.

In addition to Appendix C, Table 5 summarizes regional crop yields (kg/ha) over different LGP classes for 2000, as well as the harvested area (ha) for different crops over different LGP classes for 2000, and the predicted average difference and standard deviation in area under cultivation over different LGP classes for the 2050, based on averages of the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

The distribution of crop commodities is highly variable with a large regional variation, and a large variation is expected in the impact of climate change. To 2030 the cultivation of most crops is predicted to be in areas that are likely to undergo no changes or a moderate loss. In the longer term, the cultivation of most crops is currently in areas that are projected to undergo moderate to severe losses in LGP. These results correspond with Figure 28 and Appendix B, showing that the projected distributions of farming systems are likely to be affected by climate change. As indicated in Figure 26 and Table 3, the highland areas of Kenya and Ethiopia are among the few areas in ECA where the combination of increased temperatures and rainfall changes may lead to an extension of the growing season.

Table 5. The average yield and area under cultivation for different crops over different LGP classes for 2000, and the predicted area under cultivation over different LGP classes for the 2050 and standard deviation, based on averages of the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1

	Banana	Barley	Bean	Cassava	Coffee	Cotton	Groundnut	Maize
Average yield (t/ha)								
<120	3.46	0.98	2.00	5.67	0.87	0.29	0.69	1.20
120–180	4.33	0.96	0.98	8.34	0.45	0.92	0.71	1.51
>180	5.82	1.11	0.69	10.17	0.43	0.35	0.81	1.31
Area under cultivation (× 1000 ha)								
<120	25	97	18	50	22	16	978	289
120–180	393	447	214	502	325	67	612	2,336
>180	2,901	289	1,697	2,441	778	322	617	4,000
Standard deviation (x 1000) in area difference between 2000 and 2050								
<120	7	19	11	37	18	5	67	101
120–180	163	39	79	53	26	6	45	124
>180	201	55	82	90	86	8	22	216

	Millet	Potatoes	Rice	Sorghum	Soybean	Sugar cane	Sweet potatoes	Wheat
Average yield (t/ha)								
<120	0.29	0.00	0.64	0.70	0.46	86.33	4.01	13.26
120–180	0.47	7.51	1.62	0.93	2.57	73.81	3.55	5.18
>180	1.18	7.35	1.56	1.07	0.95	33.97	4.73	6.57
Area under cultivation (x 1000 ha)								
<120	2,015	0	268	3,961	11	48	49	22
120–180	800	66	720	1,582	5	69	290	127
>180	604	297	1,385	1,123	148	234	1,227	116
Standard deviation (x 1000) in area difference between 2000 and 2050								
<120	137	3	59	158	0	11	9	2
120–180	112	6	66	96	4	8	61	16
>180	26	13	114	146	4	4	67	16

The results in Appendix C show that in Sudan, depending on the model and scenario, 48% to 71% of the harvested area of sorghum is expected to experience a moderate decrease in growing areas by 2050. In Uganda moderate losses, for example, of 30% to 95% of the harvested area of cassava, 29% to 94% of the harvested area of sweet potatoes, and 13% to 93% of the harvested area of maize are expected.

We look at potential yield losses by looking at the average yields for 2000 over different LGP classes (Table 5). As expected with a higher LGP, most crops in ECA have higher yields. Banana, cassava and sweet potatoes are typical tropical crops and have average highest yields in areas with a prolonged LGP. In ECA, maize and potatoes are often cultivated in areas with a moderate LGP, producing their optimum average yields in areas with a LGP of 120–180 days.

As the area with a prolonged LGP is likely to decrease (Table 3), this could possibly have negative impacts on crop production. The areas with a moderate LGP (between 120 and 180 days) are likely to increase; this could possibly compensate for the production losses in the areas with prolonged LGP. As the areas with a reduced LGP (less than 120 days) are likely to increase, more production in these areas can be expected for all crops. The high standard deviation in production differences confirms the large variation between the different combinations of GCM and scenarios in the magnitude in the extent of these changes. As indicated by Thornton et al. (2009), these aggregate production changes hide a large amount of variability. However if cropping patterns and production methods do not change over time, the expected changes in production and in cultivated areas will have huge impacts on crop yields.

Impacts on livestock

Animals are a source of food, more specifically protein for human diets, income and employment (Pica-Ciamarra, 2005). The rural poor and landless, especially women, obtain a large share of their income from livestock. Livestock benefits the poor by alleviating the protein and micronutrient deficiencies prevalent in developing countries. Increased consumption of even small additional amounts of meat and milk can provide the same level of nutrients, protein and calories to the poor as a large and diverse diet of vegetables and cereals (Delgado et al., 1999). Next, the LGP change classes for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1 were overlaid with all livestock totals in order to give an estimate of the number of livestock living in the areas that are expected to be affected by climate change due to a change in growing season.

The numbers of livestock for 2000 are derived variables from the FAO Gridded Livestock of the World database (Wint and Robinson, 2007). The number of predicted livestock for 2030 and 2050 are based on trend extrapolations at country level, as described in Herrero et al. (2008), considering that: (1) population growth will drive increased demand for livestock products at a certain rate; (2) people's diets may change over time, as the proportion of livestock products ingested changes; (3) technical changes will occur over time, so that technical efficiency (killing-out percentages or milk productivity, for example) will change at a certain rate; and (4) livestock numbers will change owing to imports and exports of livestock products, depending on government policy and demand changes.

The number of livestock in countries in ECA, and the relative distribution of this livestock over the change in LGP class for 2000, 2030 and 2050 are presented in Appendix D. As indicated in Figure 28 the livestock based systems will be especially affected by changes in LGP in the marginal areas with a decrease in growing days. Most cattle, sheep and goats are located in areas that are projected to undergo 5% to 20% changes LGP.

People

In the previous sections, some details are provided on which systems and commodities are most likely to be affected by changes in LGP. In this section no attempt will be made to determine the magnitude of these implications; only some population numbers and the relative economic importance of certain commodities are presented. These results are meant as indicative—to assist in setting priorities and to determine strategies for sustainable agricultural development.

In order to give an estimate of the number of people living in the areas that are most affected by climate change, percentage changes in LGP to 2030 and 2050 were overlaid with a map with population totals. Researchers at the International Livestock Research Institute (ILRI) projected global human population totals to 2030 and 2050 by pro rata allocation of appropriate population figures, using the UN medium-variant population data for each year by country. The results in Table 6 show the projected increase in population totals for 2030 and 2050 for ECA. Whilst it lies outside the scope of this paper, the authors felt it was imperative to highlight the overriding impact that such population increases would have as drivers of change in the region. Table 4 also shows the relative population in the changes of LGP classes for ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

Most of the losses in LGP of >20% are expected in the marginal agricultural areas with predominantly livestock based systems. The relative population totals in these areas are low in most countries. However, these are the most vulnerable areas with low adaptive capacity and relatively large numbers of poor (Rass, 2006; Thornton et al., 2006). Moreover, the increase in population and thus increasing pressure on the natural resources will influence the magnitude of exposure to risks. Countries experiencing rapid rates of population growth will overstretch current public infrastructure, institutions and services. With low institutional adaptive capacity the proportion of migrant workers, rural land displacements and urban-poor households is expected to increase further, exacerbating vulnerability (Kinyangi et al., 2009).

Table 6: Human population per country for 2000, 2030 and 2050 and the distribution of predicted human population over percentage change in length of growing period classes for 2030 and 2050, for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1

	Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
2000 (× 1000)	6,270		48,750		3,710		65,590		30,550		15,970		7,720		31,440		34,840		23,490	
2030 (× 1000)	15,080		121,040		8,370		151,220		47,270		41,160		14,700		58,530		65,130		74,060	
>20% loss	0	0	0	2	13	38	1	2	0	0	2	8	0	0	29	37	0	0	0	0
5-20% loss	6	29	39	54	59	75	9	38	6	28	38	89	10	45	24	38	29	49	12	49
No change	71	94	43	61	2	13	58	71	68	84	8	54	54	90	22	33	51	71	51	82
5-20% gain	0	0	0	0	1	2	3	19	2	9	0	0	0	0	1	6	0	1	0	7
>20% gain	0	0	0	0	0	1	0	1	0	1	0	0	0	0	4	5	0	0	0	0
2050 (× 1000)	21,490		171,610		11,090		203,230		50,540		57,010		18,570		69,710		79,130		119,530	
>20% loss	0	1	0	32	36	87	1	8	0	5	12	58	0	1	35	48	0	4	0	2
5-20% loss	35	86	61	75	12	60	15	60	21	78	42	81	38	92	25	42	60	88	34	95
No change	13	65	8	36	0	3	29	56	15	71	0	26	7	62	5	26	7	38	2	62
5-20% gain	0	0	0	0	0	1	2	26	1	6	0	0	0	0	0	6	0	1	0	4
>20% gain	0	0	0	0	1	1	0	2	1	1	0	0	0	0	5	5	0	0	0	0

6.3. Implications of these impacts in the ASARECA countries

This chapter explores the implications of climate change on the agricultural sector by country. The total VOP (×1000 US$) of different commodities for ECA, and the relative contribution of countries was given in Table 4. Some results per country are given in Table 7 to Table 16.

Burundi

In Burundi most farming systems are temperate mixed rainfed systems with a long LGP, predominantly between 210–250 days (Appendix B). The main crop commodities in Burundi are bananas, sweet potatoes, cassava, beans, sugar cane, maize, sorghum, rice, potatoes and coffee (Appendix C). In terms of VOP (Table 7) bananas are the most important economic crop, contributing up to 43% of the total VOP, followed by beans, sweet potatoes and cassava.

As seen from Appendix B and C, the harvested areas of the most important economic crops are within areas that are expected to undergo changes in growing season. The results in Table 3 indicate that by 2050 the area with an LGP of 210 to 250 days is decreasing, while the area with a LGP of 180 to 210 days is expected to increase. These are those areas with the highest banana and plantain yields (Table 5), so these changes are likely to have a negative impact on the yields.

Between 35% and 86% of the population lives in areas that are expected to undergo moderate losses in LGP by 2050. None of the areas are expected to see gains in LGP.

Table 7. Burundi—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Banana & plantain	1,544,738	345	532,893,532	42.6
2	Beans	238,406	1113	265,382,434	21.2
3	Sweet potatoes	834,798	169	141,178,255	11.3
4	Cassava	709,858	166	117,879,019	9.4
5	Coffee	24,933	1305	32,529,440	2.6

DRC

Most farming systems in DRC are in the humid zone (with LGP of more than 250 days) occupying both livestock and mixed rainfed systems (Appendix B, Table 3). The main crops are cassava, sugar cane, maize and groundnuts (Appendix C). In terms of VOP (Table 8) cassava is the most important economic crop, contributing up to 45% of the total VOP, followed by maize and sugar cane.

Table 8. DRC—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006.

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Cassava	14,966,487	74	1,109,964,539	44.8
2	Maize	1,155,260	374	432,109,600	17.4
3	Sugar cane	1,531,700	141	215,499,979	8.7
4	Groundnut	366,900	382	140,165,584	5.7
5	Goat meat	18,490	6747	124,759,364	5.0

The harvested areas of the most important economic crops are within areas that are expected to undergo changes in the growing season (Appendix C). By 2050 the area with LGP of more than 250 days is expected to decrease, while the areas with LGP of 150–180 and 210–250 days are expected to increase (Table 3). The yields of cassava are highest in areas with LGP of more than 180 days (Table 5), so the changes in LGP are likely to have a negative impact on the yields of cassava. Up to three-quarters of the population can be found in regions where a moderate loss of LGP is expected by 2050.

Eritrea

Most farming systems in Eritrea are in the semi-arid zone (with LGP of less than 90 days) with predominantly livestock based systems. Most of the population lives in areas with moderate to large projected losses in LGP by 2050.

Table 9. Eritrea—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006.

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Beef	16,650	2680	44,618,171	20.3
2	Mutton	6,200	6648	41,215,409	18.8
3	Goat meat	6,070	6218	37,742,046	17.2
4	Sorghum	79,469	412	32,770,102	14.9
5	Milk	39,200	407	15,957,013	7.3

The main crops are sorghum and potatoes (Appendix C). In terms of VOP (Table 9) most important economic commodities are a range of livestock products, contributing up to 15% of the total VOP, followed by sorghum. Unfortunately, no information about the importance of teff (Eragrostis tef) is available although it is an important food grain in Eritrea. As seen from Appendix C, the harvested areas of sorghum and potatoes are within areas that are expected to experience more than 20% change in LGP. The results in Table 3 indicate that by 2050 the areas with a slightly longer LGP (90–120 and 120–150 days) are likely to decline drastically. The yields of sorghum and potatoes increase with a longer LGP (Table 5). A reduction in LGP is likely to have a negative impact on the yields of these crops.

Ethiopia

Ethiopia has a variety of farming systems, ranging from livestock based systems in semi-arid regions to mixed farming systems in temperate and humid regions (Appendix B). The livestock based systems with relatively short growing periods (less than 120 days) remain relatively constant in surface area over time. The mixed farming systems occupy an area with a wide range of growing periods (Table 3). In a few of these areas the combination of increased temperatures and rainfall changes may lead to an extension of the growing season in places. Results in Table 10 show VOP of a range of commodities in Ethiopia.

In terms of VOP (Table 10) wheat is the most important commodity, followed by maize, milk, sorghum, and coffee. Like in Eritrea, unfortunately no information about the importance of teff

Table 10. Ethiopia—the total production, average price and value of production greater than US$ 0.5 million for main agricultural commodities. Average values for years 2004 to 2006

	Commodity	Production (t	Price (US$/t)	VOP (US$)	Contribution (%)
1	Wheat	2,420,841	203	492,600,796	16.5
2	Maize	3,615,938	133	482,426,350	16.2
3	Milk	1,589,333	287	456,027,413	15.3
4	Sorghum	2,077,064	174	362,011,543	12.2
5	Coffee	195,927	1,376	269,536,579	9.1
6	Barley	1,394,535	188	262,070,314	8.8

(Eragrostis tef) is available although it is an important food grain in Ethiopia. The large variety of farming systems, commodities and integration of livestock within the production systems are clearly shown in Table 10. As seen from Appendix B, the harvested areas of wheat, maize, sorghum, coffee and barley are within areas that are expected to undergo moderate changes in LGP. Moreover, results in Table 5 show that wheat and maize can produce relatively large yields under a range of LGP classes. So the immediate impacts of climate change on the overall agricultural production in Ethiopia are likely to be less severe than in other countries in the region. However, due to large variations in the country, the local impacts will vary considerably.

Kenya

Kenya has a variety of farming systems, ranging from livestock based systems in the semi-arid regions to mixed farming systems in the semi-arid, temperate and humid regions (Appendix B). Like in Ethiopia, the farming systems occupy an area with a wide range of growing periods (Table 3).

Table 11. Kenya—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Milk	2,993,300	221	662,237,692	18.4
2	Maize	2,919,966	203	592,373,502	16.5
3	Tea	321,227	1,729	555,412,685	15.4
4	Beef	374,217	948	354,845,973	9.9
5	Potatoes	949,453	369	350,613,881	9.8

The wide range of commodities produced in Kenya and their VOP are shown in Table 11 . Maize and tea are the most important crops in terms of VOP, contributing up to respectively 17% and 16%. Both beef and milk contribute to a large extent to VOP. The meat comes from the pastoral systems and the milk from the mixed systems. Other important crops are potatoes, sweet potatoes and beans. Appendix C shows that the harvested areas of these crops are expected to undergo between 5% and 20% changes in LGP.

In Kenya a large variety of crops are grown that can produce under a range of LGP classes (Table 5). So, like in Ethiopia, the immediate impacts of climate change on overall agricultural production are likely to be less severe than in other countries in the region. However, due to large variations in the country, the local impacts will vary considerably.

Madagascar

Madagascar has both livestock based systems and mixed farming systems (Appendix B). The farming systems occupy an area with a wide range of growing periods; 32% of the surface area of Madagascar has LGP between 150 and 180 days (Table 3). The same table and Figure 26, show that LGP in Madagascar is expected to decline drastically. In terms of VOP (Table 12) rice is the most important economic crop, contributing up to 38% of the total VOP, followed by cassava. The economic importance of livestock for Madagascar is also shown in Table 12.

Table 12. Madagascar—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Rice	3,305,000	127	419,657,883	37.5
2	Milk	493,333	265	130,705,378	11.7
3	Cassava	2,150,839	51	109,298,452	9.8
4	Pork	49,467	1,912	94,590,984	8.4
5	Beef	131,875	655	86,366,256	7.7
6	Poultry	68,773	1,244	85,531,790	7.6

Rice is cultivated in the irrigated mixed farming systems, occupying a relatively small surface area. Table 5 shows that cassava grows in areas with LGP larger than 180 days. The area under LGP of more than 180 days is expected to decline (Table 3). A reduction of these areas is likely to have a negative impact on cassava yields. However, the highest yields of rice are obtained in areas with LGP of 120–180 days (Table 5), indicating that Madagascar can continue to be well suited for rice production if the necessary investments in irrigation infrastructure are made.

Rwanda

In Rwanda, most farming systems are mixed rainfed systems in high potential temperate and humid regions (Appendix B). The mixed farming systems occupy an area with a long LGP, of more than 210 days (Table 3). By 2050 the LGP is expected to decrease, however, it will still be relatively high compared to that in other ASARECA countries.

In terms of VOP (Table 13) potatoes and beans are the most important economic crop, together contributing up to 46% of the total VOP, followed by cassava, rice, sweet potatoes and sorghum. Table 5 shows that the highest yields for potatoes are obtained in areas with long LGP, more than 180 days. When LGP declines over time (Table 3), the yields of these crops are also likely to decline. However, yields for beans (Table 5) are on average highest in the LGP class of less than 120 days and the production of beans could benefit from a reduction in LGP.

Table 13. Rwanda—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Potatoes	1,223,990	93	114,177,836	23.4
2	Beans	199,310	569	113,417,189	23.2
3	Milk	120,472	401	48,317,036	9.9
4	Cassava	711,854	64	45,594,227	9.3
5	Rice	57,106	485	27,716,806	5.7
6	Sweet potatoes	856,996	32	27,715,251	5.7
7	Sorghum	193,026	142	27,330,599	5.6

Sudan

Sudan has both livestock based and mixed farming systems (Appendix B). The farming systems occupy an area with a wide range of growing periods, with 61% of the surface area of the country having LGP shorter than 90 days (Table 3). Results in Table 3 and in Figure 26 show that LGP in Sudan is expected to decline drastically.

The economic importance of livestock (the most important commodity and farming system) and livestock products in Sudan is shown in Table 14. Sorghum is the most economically important crop, contributing up to 9% of the total VOP. The yields of sorghum increase with longer LGP (Table 5). A reduction in LGP is likely to have a negative impact on the yields of these crops. More than one-third of the population (35-48%) lives in area with large projected changes in LGP by 2050 (Table 4).

Table 14. Sudan—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Cattle milk	5,354,667	631	3,378,491,236	42.9
2	Goat milk	1,512,667	630	953,590,109	12.1
3	Sorghum	4,060,667	169	685,251,036	8.7
4	Mutton	147,000	3,667	539,082,810	6.8
5	Beef	346,667	1,130	391,858,133	5.0

Tanzania

Tanzania accommodates livestock based systems and mixed farming systems (Appendix B). The farming systems occupy an area with a wide range of growing periods; 39% of the surface area of Tanzania has LGP between 150 and 180 days (Table 3). Results in Table 3 and in Figure 11 show that LGP in Tanzania is expected to decline drastically.

Maize, cassava, sorghum, rice, sweet potatoes, beans and bananas are important crops (Appendix C). In terms of VOP (Table 15) cassava is the most economically important crop, contributing up to 28% of total VOP, followed by maize. Table 5 shows high yields for cassava in areas with LGP higher than 180 days, and for maize in areas with LGP between 120–180 days. These reductions in LGP are likely to have a negative impact on the yields of these crops, especially on cassava.

Table 15. Tanzania—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Cassava	6,550,667	164	1,071,838,276	27.7
2	Maize	3,297,667	209	689,392,331	17.8
3	Beef	840,000	462	388,365,250	10.0
4	Milk	246,553	1,239	305,572,192	7.9
5	Rice	775,667	301	233,471,604	6.0

Uganda

Uganda has a variety of farming systems, ranging from livestock based systems in semi-arid regions to mixed farming systems in temperate and humid regions (Appendix B). Most farming systems are situated in areas with a prolonged growing season of more than 210 days (Table

3). A wide range of crops like banana, beans, maize, sweet potatoes, cassava, millet, coffee, sorghum and cotton are grown (Appendix C). The VOP of a range of commodities in Uganda is shown in Table 16.

Table 16. Uganda—the total production, average price and value of production for main agricultural commodities. Average values for years 2004 to 2006

	Commodity	Production (t)	Price (US$/t)	VOP (US$)	Contribution (%)
1	Cassava	5,334,000	164	872,763,897	24.0
2	Milk	731,667	462	338,278,462	9.3
3	Sweet potatoes	2,627,333	106	279,514,487	7.7
4	Beans	444,000	569	252,657,830	6.9
5	Maize	1,169,333	209	244,454,493	6.7
6	Potatoes	595,333	370	220,493,111	6.1
7	Millet	672,667	298	200,379,179	5.5

In terms of VOP (Table 16) cassava is the most important commodity, contributing up to 24% of the total VOP. Other economically important crops are sweet potatoes, beans, maize, potatoes and millet. The table shows clearly the large variety of farming systems, commodities and integration of livestock within the production systems. As seen from Appendix B, the harvested areas of these crops are currently predominantly within areas that are expected to undergo between 5% and 20% change in LGP up to 2050.

In Uganda a large variety of crops are grown that can produce under a range of LGP classes (Table 5). So, like in Ethiopia and Kenya, the immediate impacts of climate change on overall agricultural production are likely to be less severe than in other countries in the region. However, due to large variations in the country, the local impacts will vary considerably.

Low investments in research and development (R&D) and low international transfer of technology have gone hand in hand with stagnant yields in sub-Saharan Africa, resulting in a widening yield gap with the rest of the world (World Bank, 2008). To generate growth in both staple food and cash crop production, it will be essential to narrow the gap between average farm productivity and productivity potential. Barrios et al. (2008) showed that if rainfall and temperatures remained at their pre-1960s level, then a 32% gap in agricultural production would have been observed for sub-Saharan Africa in comparison to the rest of the world. Climatic change is likely to exacerbate those effects on total agricultural production.

Sharply increased investments and regional cooperation in R&D are urgent (World Bank, 2008). Besides technological innovations, information and communication technologies are essential to be able to move production improvement techniques from research institutes to the farmers.

As part of the institutional and organizational innovations the focus should be on, for example, linking farmers to output and input markets, enabling delivery of services to farmers (technical information and credit), and mechanisms to manage risks (Freeman et al., 2008; World Bank, 2008).

6.4. What are the consequences for natural resources?

The impacts of climate change on agriculture may significantly add to the development challenges of ensuring food security and poverty reduction. Success in this development challenge would be highly dependent on how the current issue of land degradation is addressed. Currently in Africa, land degradation is known to cause a decline in the productivity of the land, thereby reducing attainable and potential crop yields (InterAcademy Council, 2004). Soil nutrient depletion in sub-Saharan Africa is considered to be the main cause of declining per capita food production (Smaling et al., 1993; Stoorvogel et al., 1993; Drechsel et al., 2001). Based on data from 37 countries in sub-Saharan Africa, these studies confirm a significant relationship between population pressure, reduced fallow periods and soil nutrient depletion (including nutrient loss through erosion), indicating that in general, unsustainable dynamics exist between population, agriculture and the environment. Environmental degradation and livelihoods of smallholders are intrinsically intertwined (Buresh et al., 1997; InterAcademy Council, 2004).

Climatic change is thought to have important implications for sustainable agriculture, since continuing low rainfall can result in accelerated environmental degradation. Failure to intensify agricultural production has led to cropping in marginal lands that are more susceptible to rainfall variability and water and wind erosion (Kurukulasuriya and Rosenthal, 2003). Moreover, increases in temperature have a significant impact on the availability of water for agricultural and domestic consumption, thus it is expected to exacerbate drought conditions that are already regularly experienced (Osbahr and Viner, 2006). As outlined in Rosenzweig and Hillel (1995), a higher frequency of drought is likely to increase pressure on water availability and access for numerous reasons ranging from variable supplies to loss through increased evapotranspiration. In contrast, increases in rainfall intensity in other regions could lead to higher rates of soil erosion, leaching of agricultural pollutants, and runoff that carries livestock waste, soil and associated nutrients into surface water bodies.

Feddema (1999) showed that drying associated with global warming primarily results from increased demand for water (potential evapotranspiration) across Africa. This estimate is based on a water balance methodology that evaluates the relative impact of global warming and soil degradation on water. While there are small increases in precipitation under global warming conditions, these are inadequate to meet the increased demand for water. Furthermore, soil degradation also results in decreased water holding capacities. Based on the same water balance model, Feddema and Freire (2001) concluded that in general, reduced water holding capacities would result in increased water runoff during wet periods, resulting in higher overland flow rates and reduced groundwater recharge rates. Water lost through runoff also increases deficits during dry periods, in effect increasing the duration and intensity of drought.

Studies on water use in a growing demand for food show the total water consumption in Eastern Africa will almost double by 2025 (Rosegrant et al., 2002). The projected combined impacts of climate change and population growth suggest an alarming increase in water scarcity for many African countries, with 22 of the 28 countries considered likely to face water scarcity or water stress by 2025 (UNEP, 1999).

At the micro level, projected changes in climate may affect key soil processes such as respiration and net N mineralization and thus key ecosystem functions such as carbon (C) storage and nutrient turnover and availability (Rosenzweig and Hillel, 1995). Higher air temperatures will also be felt in the soil, where warmer conditions are likely to increase the natural decomposition of organic matter and the rates of mineralization that affect soil fertility (Rosenzweig and Hillel, 1995). Changes may be needed in fertilizer application in order to counteract these processes.

It seems obvious that shifts in rates and spatial distributions of soil erosion and deposition will occur under a changing climate. The cumulative impact of recurring droughts, cultivation of marginal lands, fuel wood and energy acquisition and overstocking has led to a drastic loss in vegetation cover. As a result, soil erosion, desertification and dust storms are emerging as significant environmental challenges (Osman-Elasha et al., 2006). Rounsevell et al. (2004) argued that the use of good land management practices, as currently understood, provides the best strategy for adaptation to the impacts of climate change on soils. However, it appears likely that land managers will need to carefully reconsider their management options, and future changes to land use are likely to result from different crop selections that adapt better to the changing conditions. Perhaps the greatest impact of climate change on soils will arise from climate-induced changes in land use and management. In light of the increased frequency of drought, farmers will further adapt by changing the selection of crops they grow. Inevitably, this will lead to shifts in the distribution of agricultural land use, which in itself will have impacts on soils, particularly on the most marginal land. Alternatively, the introduction of other management techniques that conserve soil moisture, such as reduced or no tillage, in order to maintain soil organic carbon contents will result in improved soil structure and soil fertility (Kurukulasuriya and Rosenthal, 2003).

In the ECA region, the combination of declining per capita agricultural capacity and increasing aridity is exacerbating vulnerability and rural poverty (Funk et al., 2008). Declining investments in rural development, rapidly increasing rural populations, the removal of soil nutrients through erosion, and the cultivation of most cultivatable areas limit growth in agricultural productivity. As the gap continues to grow between population increase and investment in agriculture through structural agricultural components, vulnerability and rural poverty will increase, in effect amplifying the impacts of drought on agriculture (Funk et al., 2008).

Key messages

- Many parts of ECA are likely to experience a decrease in LGP. The surface area with a short growing period (less than 90 days) will increase, especially in Madagascar and Sudan. The surface area with a prolonged growing period (more than 210 days) will decrease in most countries.
- Some of the large losses and large gains are located in areas with LGP of less than 60 days, i.e. in highly marginal areas for cropping but important for pastoralists. This implies that pastoralism will continue to be a significant livelihood option in these regions vis-à-vis crop expansion in marginal lands under current circumstances.
- By 2050 the surface area with a prolonged growing period will decrease. Most crops attain the highest yields in areas with prolonged LGP. It is therefore expected that production of the main commodities will decline.
- The combination of declining per capita agricultural capacity and increasing aridity is exacerbating vulnerability and rural poverty.
- Declining investments in rural development, rapidly increasing rural populations, the removal of soil nutrients through erosion, and the cultivation of most cultivatable areas limit growth in agricultural productivity. As the gap continues to grow between population increase and investment in agriculture through structural agricultural components, vulnerability and rural poverty will increase, in effect amplifying the impacts of drought on agriculture (Funk et al., 2008).

7. Options to cope with climate variability and climate change

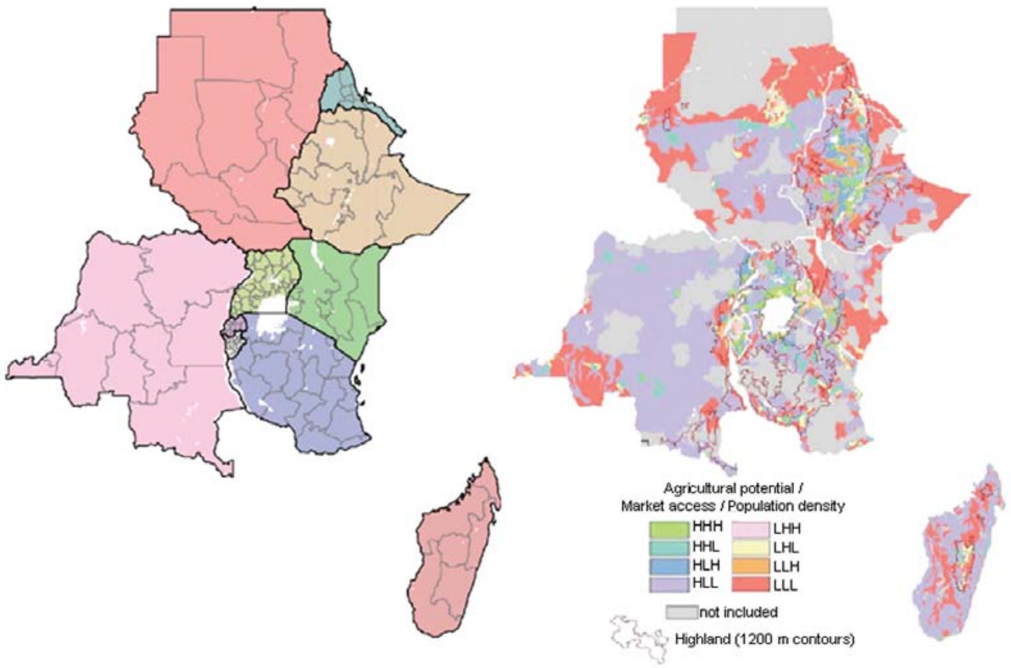
In the previous chapters current climate trends and future projections for the geographical region and the vulnerability of the agricultural sector were assessed. In this chapter the options to cope with climate variability and climate change will be discussed in relation to ASARECA's strategic plan. ASARECA makes use of 'development domains' to prioritize intervention options. Here, this approach will be clarified, before the sensitivity of the development domains as well as the intervention options are discussed. Sensitivity is formulated as the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2001). Climate-related impacts contain all the elements of climate change, including climate variability, and the frequency and magnitude of extreme events. Natural and human systems are sensitive to climate change which exerts a direct influence on water resources; agriculture (especially food security) and forestry; coastal zones and marine systems (fisheries); human settlements, energy, and industry; insurance and other financial services; and human health (IPCC, 2007b). The vulnerability of these systems varies with geographic location, time, and social, economic and environmental conditions (Boko et al., 2007).

7.1. Sensitivity of development domains

It is extremely challenging to formulate and evaluate agricultural development strategies for a region as large and diverse as ECA, and it will require multiple perspectives and thoughtful simplifications (Omamo et al., 2006). Empirical studies in Ethiopia, Kenya and Uganda (e.g. Pender et al., 1999; Pender et al., 2004; Ehui and Pender, 2005) suggest that interaction of the three socio-economic and biophysical layers—population density, agricultural potential and market access—provide good explanatory power in predicting the type of agricultural enterprises and development pathways encountered in different rural communities, as the layers are strongly related to the feasibility and attractiveness of specific development and livelihood strategies (Wood et al., 1999).

Omamo et al. (2006) used GIS tools and databases to gain a better appreciation of the regional patterns of agriculture and of agricultural development challenges and opportunities. The GIS analysis disaggregates the region into geographical units, called 'development domains', in which similar agricultural development problems or opportunities are likely to occur, based on the spatial layers population density, agricultural potential and market access. The breakdown is done by classifying each of the three factors into two values: high or low. Population densities are assumed to be high at densities of 100 persons per square kilometre or greater and low otherwise; agricultural potential is assumed to be high where LGP is 180 days or more and low otherwise; and market access is assumed to be high in locations with high level of access to at least two of the five types of market and low otherwise (Omamo et al., 2006). These development domains permit consideration of the following issues: Where are those geographic areas within and across countries in ECA in which development problems and opportunities are likely to be most similar? Where will specific types of development policies, investments, livelihood options and technologies likely be most effective? For established developmental successes in any given location in ECA, where can similar conditions be found in the region?

Figure 29 shows the development domains as developed to set strategic priorities for agricultural development in ECA (Omamo et al., 2006). Development domains are defined using consistent data and criteria across the region, thus helping diagnose development constraints and formulate and evaluate strategic intervention options in comparable ways. Agricultural development strategies demarcate priorities for action toward enhanced agricultural and overall development. Domains are described by their high and low status in sequence (agricultural potential, market access, and population density).



Note: “H” and “L” refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Figure 29. Agricultural development domains and administrative boundaries (ASARECA, 2005).

In order to obtain a better insight into the variation and importance of the development domains for different commodities and their sensitivity to climate change, we used the Development Domains Framework. This framework combines the development domains with the GOBLET tool (Quiros et al., 2009). This open source tool enables users to create user-defined development domains by using the same classes for agricultural potential, market access and population density as indicated in Figure 29. As output the tool gives summary tables of, among others, harvested area of crop commodities, livestock numbers and human populations per development domain. Appendix E shows the harvested area of crop commodities for countries in ECA (ha), and the relative distribution of these crops (%) over the development domains. Appendix F shows the total number of animals for countries in ECA, and the relative distribution of these animals (%) over the development domains. Although Appendices E and F are simplified versions of the agricultural situation, they give some insights into agricultural development options per country or per commodity, especially in combination with the other tables in this report. The results are in line with the priority commodities as indicated by Omamo et al. (2006). In the following paragraphs we discuss some of the results presented in Appendix E and F.

According to the analysis by Omamo et al. (2006), the high agricultural potential, low market access, low population density (HLL) domain emerges as having by far the highest growth potential in the region. Large segments of the countries in ECA fall in this domain and it produces a large share of all crop commodities (Omamo et al., 2006). DRC, Tanzania and Uganda especially seem to have development options. In DRC the VOP is predominantly determined by cassava (Table 8). In Rwanda (Table 13), Uganda (Table 16) and Tanzania (Table 15) cassava is also an important economic crop. The highest yields are in areas with prolonged LGP (more than 180 days) (Table 5). These areas are projected to decline in surface extent, indicating that crop yields will decline as well. Cassava has the ability to grow on marginal lands where cereals and other crops do not grow well; it can tolerate drought and can grow in low-nutrient soils. Due to the fact that cassava is grown in marginal areas, in many of the development domains where it is currently grown there are possibilities for market development. It is therefore essential to look at possibilities to improve crop production to reduce the existing yield gap. One example is by increasing the adoption of improved varieties by farmers through formal and informal seed supply chains and systems and the other is by promoting better crop and land management techniques and pest control techniques.

Omamo et al., (2006) indicate that the domains LLL (low agricultural potential, low market access, low population density), HHH (high agricultural potential, high market access, high population density), and HLH (high agricultural potential, low market access, high population density) are of lower priority than the HLL domain (high agricultural potential, low market access, low population density), as development in these domains is likely to face a trade-off between growth and sustainability. Burundi and Rwanda have large areas categorized as

HHH and HLH (Figure 29). In Burundi most crops are grown in locations that over time are projected to be suitable for agricultural production, without much loss of LGP. Rwanda also will not experience that much loss in LGP (Figure 26, Table 3). Omamo et al. (2006) stresses the current importance of the HHH and HLH zones as suppliers of milk, poultry, bananas, fruits and vegetables, wheat, barley and legumes. Development interventions in these domains should focus on increasing productivity growth by focusing on natural resources management (Omamo et al., 2006). Many of the technologies required for addressing problems such as soil nutrient depletion, soil erosion, pests, and weeds already exist. Most of these technologies are knowledge intensive, implying the need for structures and processes that promote sustained learning among not only farmers but also service providers likely to be involved in successful technology adoption.

In LLL zones, concerns arise from the fragile and uncertain environments. Eritrea and Sudan are both countries with predominantly a short LGP, similar to large regions of Ethiopia, Kenya, Madagascar and Tanzania (Figure 26, Table 3). In these areas cropping is largely impossible and certainly highly risky, both with regard to production and environmental degradation; pastoralism therefore dominates. In such environments coping strategies assume even greater importance, but are perhaps less diversified due to the more restricted asset base and the more marginalized nature of such communities (Cooper et al., 2008). Traditional coping mechanisms exist, for instance pastoralists over much of East Africa know that their ability to move livestock herds rapidly and over long distances improves the chances of foraging and hence survival for the livestock (Mude et al., 2007). However, as mobility is increasingly restricted due to factors like conflicts, the expansion of agricultural cultivation in the semi-arid regions and increased competition over land, Kinyangi et al. (2009) observed that much of the existing coping capacity will need to give way to increased adaptive capacity in order to accommodate escalating demands for resources among vulnerable communities and environments.

The LHH (low agricultural potential, high market access, high population density), HHL (high agricultural potential, high market access, low population density), LLH (low agricultural potential, low market access, high population density), and LHL (low agricultural potential, high market access, low population density) domains are low priority, as agriculture-based growth in these domains is unlikely to be large enough to warrant major agricultural development investments (Omamo et al., 2006). Ethiopia, Kenya and Madagascar have large areas classified as these domains. However, in Ethiopia and Kenya the main economic crop commodities are grown over a range of development domains. In certain development domains there are still opportunities to improve access to markets. A large share of the crops is grown in areas with a lower agro-ecological potential; these areas are especially vulnerable to climate change. In these areas it is important to look at options to increase crop production. In Madagascar the main economic crop commodities are rice, cassava and sugar cane grown in marginal agricultural potential, low market access and low population areas. As indicated by Omamo et al. (2006) typical development options in these areas are diversification, low-input crops and livestock intensification.

7.2. Sensitivity of intervention options promoted by ASARECA

Based on the potential for agricultural growth, Omamo et al. (2006) identified agricultural development priorities within ECA agricultural development domains. The development domains HHH and HHL have the greatest options for commercialization and diversification; HLH and HLL have more limited options, technology adoption and commercialization. In all domains, as development options high-input cereals such as maize, rice and wheat are indicated (Omamo et al., 2006). To look at the sensitivity of these options, these development options are compared with NAPA which identified for each country the urgent and immediate needs to adapt to current threats from climate change. Comparing the development priorities and options with these NAPAs (NAPA-DRC, 2006; NAPA-Burundi, 2007; NAPA-Eritrea, 2007; NAPA-Ethiopia, 2007; NAPA-Madagascar, 2007, NAPA-Rwanda, 2007; NAPA-Susan, 2007; NAPA-Tanzania, 2007; NAPA-Uganda, 2007), a number of similar priorities and options are given stressing the fact that adapting to climate change is very similar to dealing with current variability in rainfall and promoting good agricultural practice (Table 17).

The information in Table 17 shows the agricultural development priorities and within ECA development domains and compares the priorities and options with the NAPA reports. The NAPA reports of many countries mention as potential adaptation measures agricultural research and transfer of technology; improved pest and disease forecast, and control of pests, weeds and diseases; improved soil and water management; create awareness, educational and outreach activities to change management practices to those suited to climate change; and storage of agriculture products. Furthermore, the options are comparable, as the NAPA reports stress the promotion of intensive agriculture and animal husbandry, and popularization of zero-grazing techniques.

The NAPA reports include more detailed lists of agricultural development and livelihood options, like popularize short cycle and drought resistant food crop (e.g. Burundi and Rwanda); identify and popularize the breeding of species adapted to local climate conditions (e.g. Burundi); switch to different cultivars (e.g. Ethiopia and Uganda); establish seed banks (e.g. DRC); and improve pest and disease forecast and control (e.g. DRC and Ethiopia). In other words, agricultural development is essential for climate change adaptation. As indicated by Stern (2006) adaptation should be an extension of good development practice and should reduce vulnerability by promoting growth and diversification of economic activities, investing in health and education, and enhancing resilience to disasters and improving disaster management.

Besides looking at the NAPA reports, it is useful to compare the development options with the findings of the previous chapters. Based on these findings, Table 18 gives an indication of the sensitivity of intervention options. Appendix C indicates that crop commodities are currently grown in areas that are likely to experience losses in LGP. The areas were maize, a staple crop in many countries in the region, is currently cultivated is projected to experience moderate losses in LGP. And for wheat production in Kenya, one of the main wheat growing countries in ECA, about 28% to 66% of the current planted area will experience 5% to 20% losses in LGP depending on the climate change scenarios. In case high-input cereals are promoted, one should take into account projected climate changes and possible consequences of suitability of promoted varieties. ECA has almost no area of improved varieties under production (World Bank, 2008). Moreover, to deal with variability in rainfall appropriate land management and pest control techniques will need to go hand in hand with the introduction of seed-supply chains and systems of these high-input cereals.

The development domains LHH and LHL have commercialization options for high input and labour intensive production. In these domains, high-input cereals, perishable cash crops and intensive livestock (dairy) are indicated as development options, if there are investments in irrigation (Omamo et al., 2006). Some NAPAs, like for Ethiopia, Kenya and Uganda, bring up the promotion of irrigation. However, studies on water use in a growing demand for food show the total water consumption in Eastern Africa will almost double by 2025 (Rosegrant et al., 2002). The projected combined impacts of climate change and population growth suggest an alarming increase in water scarcity for many African countries, with 22 of the 28 countries considered likely to face water scarcity or water stress by 2025 (UNEP, 1999).

The development domains LLH and LLL have a few options like low-input cereals and limited livestock intensification. Intervention options in these areas are most likely to focus on overall improvement of nutrition and genetics of ruminant livestock (Thornton et al., 2008; World Bank, 2008).

The information in Table 17 and Table 18 excludes options related to mitigating climate change through agriculture. Possible approaches are sequestering carbon by reforestation and afforestation, rehabilitating degraded grasslands, rehabilitating cultivated soils, and promoting conservation agriculture (FAO, 2008; World Bank, 2008). These approaches could be intervention options across the development domains and could potentially diversify specific development and livelihood strategies. In addition, opportunities for farmers in ECA to get involved in other payment for environmental services, like watershed protection and wild biodiversity conservation is also not dealt with (FAO, 2007). Several funds within the World Bank and the UN system finance specific activities aimed at reducing GHG emissions and increasing resilience to the negative impacts of climate change. Many mitigation actions that would have high payoffs also represent good options for adaptation within the food and agriculture sectors of low-income developing countries. It may be possible to obtain additional resources from bilateral and multilateral aid agencies, which are becoming increasingly interested in investing development funds in adaptive responses to climate change (FAO, 2008).

Key messages

- The HLL domain emerges as having by far the highest growth potential in the region. DRC, Tanzania and Uganda especially seem to have options for development.
- Cassava is an important economic crop. It is essential to look at possibilities to improve crop production to reduce the existing yield gap. Production of cassava could be improved by increasing the adoption of improved varieties by farmers through formal and informal seed-supply chains and systems or by promoting better crop and land management techniques, or pest control techniques.
- In LLL domains, concerns arise from the fragile and uncertain environments where pastoralism is dominant. Traditional coping mechanisms exist. However, as mobility is increasingly restricted due to factors like conflicts, the expansion of agricultural cultivation in the semi-arid regions and increased competition over land, much of the existing coping capacity will need to give way to increased adaptive capacity in order to accommodate escalating demands for resources among vulnerable communities and environments.
- If high-input cereals are promoted, one should take into account projected climate changes and possible consequences of suitability of promoted varieties. ECA has almost no area of improved varieties under production. Moreover, to deal with variability in rainfall, appropriate land management and pest control techniques will need to go hand in hand with the introduction of seed-supply chains and systems of these high-input cereals.
- The development domains LLH and LLL have few options like low-input cereals and limited livestock intensification. Intervention options in these areas are most likely to focus on overall improvement of nutrition and genetics of ruminant livestock.

Table 17. Agricultural development priorities within ECA development domains (adapted from Omamo et al., 2006), compared with priorities indicated in the National Adaptation Programme of Action (NAPA) reports in ECA

				Example locations in ECA and potential agricultural development/livelihood options	
				Population density	NAPA
Agricultural potential	Agricultural market	Priorities	NAPA	High	
High	High	*Productivity growth* • Agricultural research and extension systems • Weed and pest control • Soil and water management • Awareness raising and consensus building on biotechnology-related opportunities and risks *Market improvement* • Market intelligence (domestic, regional and international) *Linkages with non-agriculture* • Storage, processing, distribution • Agro-industrialization	 9 4, 9 2, 3, 4, 5, 7, 8 1, 2, 3, 7, 8, 9 6 	*Options* • High-input cereals (for example, maize, rice, wheat) • Perishable cash crops (for example, vegetables, fruits, flowers, ornamentals) • Intensive livestock (for example, dairy, chickens, pigs) • Non-perishable cash crops (for example, coffee, tea)	 2, 6, 7 2, 6, 7 1, 2, 6, 7, 8
				Low *Options* As for high population density plus more extensive high-value options (for example cotton, tea, oil crops, fruits)	 2, 6, 7
	Low	*Productivity growth* • Agricultural research and extension systems • Weed and pest control • Soil and water management • Awareness raising and consensus building on biotechnology-related opportunities and risks *Market improvement* • Market development (infra-structure, market information systems, credit institutions, and the like) *Linkages with non-agriculture* • Storage, processing, distribution	 9 4, 9 2, 3, 4, 5, 7, 8 1, 2, 3, 7, 8, 9 	**High** *Options* • High-input cereals (for example, maize, rice, wheat) • Non-perishable cash crops	 2, 6, 7
				Low *Options* • Intensification in non-perishable crops (cereals, oilseeds, tea, coffee) • Livestock intensification; improved grazing areas	 2, 6, 7 1, 2, 6, 7, 8
Low	High	*Productivity growth* • Agricultural research and extension systems • Weed and pest control • Soil and water management • Awareness raising and consensus building on biotechnology-related opportunities and risks • Irrigation *Market improvement* • Market intelligence (domestic, regional, international) *Linkages with non-agriculture* • Storage, processing, distribution	 6 9 4, 9 2, 3, 4, 5, 7, 8 1, 2, 3, 7, 8, 9 6	**High** *Options* • With irrigation investment - High-input cereals - Perishable cash crops - Dairy, intensive livestock • Without irrigation investment - Low-input cereals	 4, 9 4, 9 4, 9 1, 6
				Low *Options* • With irrigation investment - High-input cereals - Perishable cash crops - Dairy, intensive livestock • Without irrigation investment - Low-input cereals - Livestock intensification, improved grazing areas - Woodlots	 4, 9 4, 9 4, 9
	Low	*Productivity growth* • Agricultural research and extension systems • Weed and pest control • Soil and water management • Raising awareness and building consensus on biotechnology-related opportunities and risks *Market improvement* • Market development (infrastructure, market information systems, credit institutions, and the like) *Linkages with non-agriculture* • Storage, processing, distribution	 9 4, 9 2, 3, 4, 5, 7, 8 1, 2, 3, 7, 8, 9 6	**High** *Options* • Low-input cereals • Limited livestock intensification • Emigration	 1, 6
				Low *Options* • Low-input cereals • Livestock intensification, improved pasture management, improved nutrition, breeding for disease resistance	 1, 6

Where 1 = Burundi; 2 = DRC; 3 = Eritrea; 4 = Ethiopia; 5 = Madagascar; 6 = Rwanda; 7 = Sudan; 8 = Tanzania; 9 = Uganda.

Table 18. Agricultural development priorities within ECA development domains and sensitivity to climate change (adapted from Omamo et al., 2006).

			Example locations in ECA and potential agricultural development/livelihood options	
			Population density	**Climate sensitivity**
Agricultural potential	**Agricultural market**	**Priorities**	**High**	
High	High	*Productivity growth* • Agricultural research and extension systems • Weed and pest control • Soil and water management • Awareness raising and consensus building on biotechnology-related opportunities and risks *Market improvement* • Market intelligence (domestic, regional and international) *Linkages with non-agriculture* • Storage, processing, distribution • Agro-industrialization	*Options* • High-input cereals (for example, maize, rice, wheat) • Perishable cash crops (for example, vegetables, fruits, flowers, ornamentals) • Intensive livestock (for example, dairy, chickens, pigs) • Non-perishable cash crops (for example, coffee, tea)	*** *** ** ***
			Low	
			Options • As for high population density plus more extensive high-value options (for example cotton, tea, oil crops, fruits)	***
	Low	*Productivity growth* • Agricultural research and extension systems • Weed and pest control • Soil and water management • Awareness raising and consensus building on biotechnology-related opportunities and risks *Market improvement* • Market development (infrastructure, market information systems, credit institutions, and the like) *Linkages with non-agriculture* • Storage, processing, distribution	**High**	
			Options • High-input cereals (for example, maize, rice, wheat) • Non-perishable cash crops	*** **
			Low	
			Options • Intensification in non-perishable crops (cereals, oilseeds, tea, coffee) • Livestock intensification; improved grazing areas	*** *
Low	High	*Productivity growth* • Agricultural research and extension systems • Weed and pest control • Soil and water management • Awareness raising and consensus building on biotechnology-related opportunities and risks • Irrigation *Market improvement* • Market intelligence (domestic, regional, international) *Linkages with non-agriculture* • Storage, processing, distribution	*Options* • With irrigation investment - High-input cereals - Perishable cash crops - Dairy, intensive livestock • Without irrigation investment - Low-input cereals	 *** *** ** *
			Low	
			Options • With irrigation investment - High-input cereals - Perishable cash crops - Dairy, intensive livestock • Without irrigation investment - Low-input cereals - Livestock intensification, improved grazing areas - Woodlots	 *** *** * * ** *
	Low	*Productivity growth* • Agricultural research and extension systems • Weed and pest control • Soil and water management • Raising awareness and building consensus on biotechnology- related opportunities and risks *Market improvement* • Market development (infrastructure, market information systems, credit institutions, and the like) *Linkages with non-agriculture* • Storage, processing, distribution	**High**	
			Options • Low-input cereals • Limited livestock intensification • Emigration	* ** -
			Low	
			Options • Low-input cereals • Livestock intensification, improved pasture management, improved nutrition, breeding for disease resistance	 * **

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Appendix

Appendix A: Current climate adaptation tools and approaches to estimate the impacts.

Appendix B: Area distribution of farming systems for countries in ECA, and percentage of these areas over different classes of length of growing periods for the years 2000, 2030 and 2050, for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

Appendix C: The harvested area of crop commodities for countries in ECA (ha), and the relative percentual distribution of these crops (%) over the change in length of growing period classes over the years 2030 and 2050, for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

Appendix D: The number of (predicted) livestock for countries in ECA, and the relative distribution of this livestock over the change in length of growing period class for the years 2000, 2030 and 2050, for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

Appendix E: The harvested area of crop commodities for countries in ECA (ha), and the relative percentual distribution of these crops (%) over the development domains. Note: “H” and “L” refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Appendix F: The total number of animals for countries in ECA, and the relative percentual distribution of these animals (%) over the development domains. Note: “H” and “L” refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Appendix A:

Current climate adaptation tools and approaches to estimate the impacts.

This section provides a list of climate adaptation tools and approaches to estimate the impacts of climate change and variability; they are all indicated in Chapter 3 or other sections of the text.

Agricultural Catchments Research Unit (ACRU)

More information: http://www.beeh.unp.ac.za/acru

The Agricultural Catchments Research Unit (ACRU) is a model that can be used at the catchment or sub-catchment level to study the impact of climate change and enhanced CO2 conditions on crop yield and water balances. It is a multipurpose model that integrates water budgeting and runoff components of the terrestrial hydrological system with risk analysis. The model can be applied in crop yield modelling, design hydrology, reservoir yield simulation and irrigation water demand/supply, regional water resources assessment, planning optimum water resource allocation and utilization, climate change, land use and management impacts, and resolving conflicting demands on water resources. The ACRU model uses daily multilayer soil-water budgeting and has been developed essentially into a versatile total evaporation model. It has therefore been structured to be highly sensitive to climate and to land cover/use changes on the soil water and runoff regimes, and its water budget is responsive to supplementary watering by irrigation, to changes in tillage practices or to the onset and degree of plant stress.

Agricultural Production Systems sIMulator (APSIM)

More information: www.apsim.info/apsim/

The Agricultural Production Systems sIMulator (APSIM) is an effective tool for analysing whole-farm systems, including crop and pasture sequences and rotations, and for considering strategic and tactical planning. APSIM allows users to improve understanding of the impact of climate, soil types and management on crop and pasture production. It is a powerful tool for exploring agronomic adaptations.

APSIM is a modelling framework with the ability to integrate models derived in fragmented research efforts. This enables research from one discipline or domain to be transported for the benefit of some other discipline or domain. It also facilitates comparison of models or sub-models on a common platform. This functionality uses a ‘plug-in-pull-out’ approach to APSIM design. The user can configure a model by choosing a set of sub-models from a suite of crop, soil, and utility modules. Any logical combination of modules can be simply specified by the user ‘plugging in’ required modules and ‘pulling out’ any modules no longer required. Its crop simulation models share the same modules for the simulation of soil, water and nitrogen balances. APSIM can simulate more than 20 crops and forests (e.g. alfalfa, eucalyptus, cowpea, pigeon pea, peanuts, cotton, lupine, maize, wheat, barley, sunflower, sugar cane, chickpea and tomato).

CENTURY

More information: http://www.nrel.colostate.edu/projects/century/

The CENTURY model is a general model of plant–soil nutrient cycling which is used to simulate carbon and nutrient dynamics for different types of ecosystems including grasslands, agricultural lands, forests and savannahs. The model comprises a soil organic matter/ decomposition sub-model, a water budget model, a grassland/crop sub-model, a forest production sub-model, and management and events scheduling functions. It computes the flow of carbon (C), nitrogen (N), phosphorus (P) and sulphur (S) through the model's compartments. The minimum configuration of elements is C and N for all the model compartments. The organic matter structure for C, N, P and S are identical; the inorganic components are computed for the specific inorganic compound.

Climate Matching Made Easy (CLIMEX)

More information: www.climatemodel.com/climex.htm

Climate Matching Made Easy (CLIMEX), developed by CSIRO Entomology, predicts the potential distribution and relative abundance of species in relation to climate. CLIMEX is used to examine the distribution of insects, plants, pathogens and vertebrates for a variety of purposes, including biogeography, quarantine, biological control and impacts of changes in climate and climate variability. Using climate information and knowledge about the biology and distribution of a particular species in its original habitat, CLIMEX enables a rapid, reliable assessment of the risks posed by the introduction of different organisms, and can be used to predict locations to which it could spread.

CLIMWAT

More information: http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGL/AGLW/cropwat.stm

CLIMWAT is a climatic database that is used in combination with the computer program CROPWAT 9 and allows the ready calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatologically stations worldwide. The CLIMWAT database includes data from a total of 3262 meteorological stations from 144 countries. The climatological data included are maximum and minimum temperature, mean daily relative humidity, sunshine hours, wind speed, precipitation and calculated values for reference evapotranspiration and effective rainfall. The database is meant as a practical tool to assist irrigation and agricultural specialists in the planning and management of irrigated and rainfed agriculture in combination with the CROPWAT program.

Collaborating on Climate Adaptation (weADAPT)

More information: www.weadapt.org/

Collaborating on Climate Adaptation (weADAPT) is a space for sharing information, guidance and experience on assessing and communicating risk and adapting to climate change in multi-stressor environments. The open platform contains core themes on framing adaptation, risk monitoring, decision screening, and communication, as well as tools and methods, worked examples and useful guidance to aid adaptation planning and implementation.

This open platform is a work in progress. The intention is to include a collection of software tools (e.g. risk mapping, MCA), databases (e.g. criteria, adaptation actions), guidance, examples/prototypes and communications. It is intended to support analysts who advise a range of final users in multiple sectors at multiple scales. The risk modules tend to focus on fairly immediate links between climate episodes and trends and impacts affecting environmental services, economic activities and livelihoods. The tool platform will be designed to clarify choices in decision making and not prescribe perfect solutions to specific risks. It has adopted a social learning and process approach to adaptation planning and decision making which incorporates project details, vulnerability data and stakeholder engagement.

CROPWAT

More information: http://www.fao.org/ag/AGL/aglw/cropwat.htm

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO. Its main functions are to calculate reference evapotranspiration, crop water requirements and crop irrigation requirements in order to develop irrigation schedules under various management conditions and scheme water supply and to evaluate rainfed production, drought effects and efficiency of irrigation practices. CROPWAT is a practical tool to help agro-meteorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation. Calculations of crop water requirements and irrigation requirements are carried out with inputs of climatic and crop data. Standard crop data are included in the program and climatic data can be obtained for 144 countries through the CLIMWAT database. The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided.

Decision Support System for Agro technology Transfer (DSSAT)

More information: http://www.icasa.net/dssat/

Decision Support System for Agro technology Transfer (DSSAT) is a software package integrating the effects of soil, crop phenotype, weather and management options that allows users to ask 'what if' questions and simulate results by conducting, in minutes on a desktop computer, experiments which would consume a significant part of an agronomist's career. It has been in use for more than 15 years by researchers in over 100 countries. DSSAT is a microcomputer software product that combines crop, soil and weather databases into standard formats for access by crop models and application programs. The user can then simulate multi-year outcomes of crop management strategies for different crops at any location in the world. DSSAT also provides for validation of crop model outputs; thus allowing users to compare simulated outcomes with observed results. Crop model validation is accomplished by inputting the user's minimum data, running the model, and comparing outputs. By simulating probable outcomes of crop management strategies, DSSAT offers users information with which to rapidly appraise new crops, products and practices for adoption.

DIVA-GIS

More information: www.diva-gis.org/

DIVA-GIS is a mapping program, sometimes called geographic information system (GIS) that has many uses. It is particularly useful for mapping and analysing biodiversity data, such as the distribution of species, or other 'point-distributions'. The analytical functions of DIVA allow mapping richness and diversity, (including based on DNA data; mapping the distribution of specific traits; identification of areas with complementary diversity; and analysis of spatial autocorrelation). Diva can also extract and use climatic data for the prediction of the presence of species under different climatic regimes and present the climatic environment of data collection sites hence enabling DIVA to be used widely for the study of the biodiversity.

Flora Map

More information: http://www.floramap-ciat.org/download/theory.pdf

Flora Map system is a system based tool for calculating the probability that a climate record belongs to a multivariate normal distribution described by the climates at the collection points of a calibration set of organisms. It was designed for naturally occurring plant species; its use may be extended to cover the natural occurrence of any organism whose distribution is largely determined by climate. It uses a set of interpolated climate surfaces, a method for calculating the probability model, and a method for mapping the climate probabilities over the climate surface.

MAGICC/SCENGEN

More information: http://www.cgd.ucar.edu/cas/wigley/magicc/

MAGICC/SCENGEN is a user-friendly software package that takes emissions scenarios for greenhouse gases, reactive gases, and sulphur dioxide as input and gives global mean temperature, sea level rise, and regional climate as output. MAGICC is a coupled gas cycle/climate model. It has been used in all IPCC reports to produce projections of future global mean temperature and sea level change, and the current version reproduces the results given in the IPCC Third Assessment Report. MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single software package. The software allows the user to determine changes in greenhouse gas concentrations, global mean surface air temperature, and sea level resulting from anthropogenic emissions. SCENGEN constructs a range of geographically explicit climate change projections for the globe using the results from MAGICC together with AOGCM climate change information from the CMIP3/AR4 archive.

National Adaptation Programme of Action (NAPA)

More information: www.napa-pana.org/

The purpose of developing a National Adaptation Programme of Action (NAPA) is to identify the urgent and immediate needs of a country to adapt to current threats from climate change. Addressing these needs will expand the coping range and enhance resilience in a way that will promote the capacity to adapt to current climate variability and extremes, and consequently to future climate change. The process is uniquely for the least developed countries (LDCs) as they have the least capacity to deal with the impacts of climate. It aims to facilitate the delivery of technical assistance to NAPA teams formulating their NAPA documents, particularly with regards to the synthesis of existing vulnerability and adaptation information, and the formulation of relevant adaptation projects profiles. It provides multi-sectoral information aimed at the programme and project level for LDCs within the NAPA process.

Providing REgional Climates for Impacts Studies (PRECIS)

More information: http://precis.metoffice.com/

Providing REgional Climates for Impacts Studies (PRECIS) is developed at the Hadley Centre, UK Meteorological Office. PRECIS is a regional climate modelling system, designed to run on a Linux based PC. PRECIS can be easily applied to any area of the globe to generate detailed climate change projections.

PRECIS was developed in order to help generate high-resolution climate change information for as many regions of the world as possible. The intention is to make PRECIS freely available to groups of developing countries in order that they may develop climate change scenarios at national centres of excellence, simultaneously building capacity and drawing on local climatologically expertise. These scenarios can be used in impact, vulnerability and adaptation studies.

A regional climate model (RCM) is a downscaling tool that adds fine scale (high resolution) information to the large-scale projections of a global general circulation model (GCM). GCMs are typically run with horizontal scales of 300 km; regional models can resolve features down to 50 km or less. This makes for a more accurate representation of many surface features, such as complex mountain topographies and coastlines. It also allows small islands and peninsula to be represented realistically, where in a global model their size (relative to the model grid box) would mean their climate would be that of the surrounding ocean.

The tool uses GCM to provide grid-scale averages of spatio-temporal hydro-climatic state variables as well as soil hydrology and thermodynamics, and some vegetation dynamic variables.

Simulated Weather Data for Crop Modeling and Risk Assessment (MarkSim)

More information: www.iwmi.cgiar.org

Simulated Weather Data for Crop Modeling and Risk Assessment (MarkSim), developed by the International Center for Tropical Agriculture (CIAT), is a computer tool that generates simulated data for crop modelling and risk assessment. MarkSim is a stand alone model with two basic parts. Part one is a stochastic rainfall generator which drives the weather simulation model. The second part of MarkSim is a set of surface parameters that can be sampled by users; this part gives the MarkSim spatial dimension. The MarkSim model is capable of simulating four weather parameters: radiation, maximum temperature, minimum temperature and rainfall.

START, the global change System for Analysis, Research and Training

More information: www.start.org

START (the global change SysTem for Analysis, Research, and Training) is a framework of collaborating organizations that develops scientific capacity and generates knowledge to support decisions for building resilience to global environmental change and enabling sustainable development. The START framework consists of regional science committees, research centres, research nodes and secretariats as well as participating scientists located throughout the developing and developed world.

Statistical DownScaling Model (SDSM)

More information: www.sdsm.org.uk/

This tool is developed by the Environment Agency in the UK. The Statistical DownScaling Model (SDSM) is a decision support tool for assessing local climate change impacts using a robust statistical downscaling technique. This computer-based information tool is open-source and is aimed at donors, governments and impact assessors. SDSM facilitates the rapid development of multiple, low-cost, single-site scenarios of daily surface weather variables under current and future regional climate forcing. The tool provides daily, transient, climate risk information for impact assessment over the 1961–2100 time horizon. It has been primarily used for water resource management, though is applicable to multiple sectors. After calibration of data, the tool provides rapid assessments to assist impacts and adaptation analysis.

weADAPT

More information: http://www.weadapt.org

weADAPT is a collaboration between leading organizations on climate adaptation and includes new and innovative tools and methods, data sets, experience and guidance. weADAPT provides guidance by pooling expertise from a wide range of organizations that contribute to adaptation science and practice.

World Development Indicators

More information: http://go.worldbank.org/

WDI (World Development Indicators) is the World Bank's annual compilation of data about development. It provides statistical data and quantity data hence helping to set baselines, identify effective public and private actions, set goals and targets, monitor progress and evaluate impacts. The publication allows one to view development not just in terms of economic outputs, but also through the welfare of people, the condition of the environment, and the quality of governance. The extensive collection of development data includes social, economic, financial, natural resources and environmental indicators for more than 40 years, 1960 to 2006, where data are available (2006 data for selected indicators only).

Appendix B: Area distribution of farming systems for countries in ECA, and percentage of these areas over different classes of length of growing periods for the years 2000, 2030 and 2050, for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Livestock based																					
Semi-arid	2000 (1000 ha)	0		9,181		7,731		47,829		38,323		31,076		0		176,268		23,286		1,684	
	2030 (1000 ha)	0		10,623		7,923		46,835		37,642		25,815		0		163,474		22,128		878	
	>20% loss (%)	0	0	0	0	29	53	3	16	1	13	1	76	0	0	29	35	0	1	0	0
	5-20% loss (%)	0	0	2	3	13	34	10	16	9	23	0	38	0	0	9	14	9	21	0	4
	No change (%)	0	0	1	3	3	9	8	18	16	26	0	7	0	0	4	16	3	15	0	3
	5-20% gain (%)	0	0	0	0	2	4	6	10	9	25	0	0	0	0	1	3	0	1	0	1
	>20% gain (%)	0	0	0	0	3	6	3	7	3	6	0	0	0	0	5	9	0	0	0	0
	2050 (1000 ha)	0		8,465		7,966		45,525		37,451		23,513		0		160,945		21,743		495	
	>20% loss (%)	3	15	1	6	3	9	0	0	53	62	0	1	0	0	0	0	0	0	0	0
	5-20% loss (%)	10	16	6	13	11	17	0	0	15	24	9	17	0	0	0	0	0	0	0	0
	No change (%)	7	14	7	11	0	1	0	0	7	20	1	10	0	0	0	0	0	0	0	0
	5-20% gain (%)	5	7	3	10	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	2	8	1	4	0	0	0	0	14	18	0	0	0	0	0	0	0	0	0	0
Temperate	2000 (1000 ha)	0		666		113		1,383		2,296		450		0		63		1,104		85	
	2030 (1000 ha)	0		0		14		105		1,227		144		0		0		457		0	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	No change (%)	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050 (1000 ha)	0		0		14		23		867		71		0		0		329		0	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	No change (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humid	2000 (1000 ha)	0		24,596		0		115		6		10		0		4,356		4,800		891	
	2030 (1000 ha)	0		14,582		0		173		68		56		9		3,732		2,754		383	
	>20% loss (%)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	0	3	5	0	0	0	0	0	0	0	0	0	0	1	2	2	2	0	2
	No change (%)	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050 (1000 ha)	0		8,233		0		217		75		56		9		3,574		2,178		223	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	0	0	0	0	0	0	0	2	3	1	2	0	0	0	0	0	0	0	0
	No change (%)	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B: Area distribution of farming systems for countries in ECA, and percentage of these areas over different classes of length of growing periods for the years 2000, 2030 and 2050 - continuation

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Mixed rainfed																					
Semi-arid	2000 (1000 ha)	32		548		1,902		18,053		5,992		7,229		424		46,919		32,376		3,471	
	2030 (1000 ha)	0		3,619		2,018		24,612		7,078		13,888		202		60,493		33,089		4,118	
	>20% loss (%)	0	0	0	0	1	12	0	4	0	1	0	11	0	0	0	2	0	1	0	1
	5-20% loss (%)	0	0	1	1	8	16	5	14	1	7	0	23	2	8	7	26	14	34	2	19
	No change (%)	0	0	0	1	0	4	6	16	5	8	0	7	0	6	2	20	2	23	1	15
	5-20% gain (%)	0	0	0	0	0	0	1	4	0	4	0	0	0	0	0	3	0	0	0	4
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050 (1000 ha)	0		7,461		2,032		28,251		7,635		16,849		60		63,236		35,456		4,160	
	>20% loss (%)	0	4	0	0	1	11	0	0	0	4	0	1	0	0	0	0	0	0	0	0
	5-20% loss (%)	6	15	1	3	4	13	0	0	21	48	19	28	1	4	0	0	0	0	0	0
	No change (%)	6	15	3	3	0	2	0	0	5	29	2	11	0	2	0	0	0	0	0	0
	5-20% gain (%)	1	5	0	2	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperate	2000 (1000 ha)	1,826		1,287		246		26,571		4,759		1,630		1,591		88		3,950		1,395	
	2030 (1000 ha)	1,001		972		72		18,570		4,094		920		963		32		1,632		404	
	>20% loss (%)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	1	31	0	0	0	1	1	12	0	6	0	2	3	38	0	0	1	1	0	2
	No change (%)	9	39	0	0	0	0	6	14	1	6	0	1	2	37	0	0	0	1	0	1
	5-20% gain (%)	0	0	0	0	0	0	0	5	0	1	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050 (1000 ha)	460		572		14		13,890		3,707		416		668		32		1,289		286	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	1	8	0	2	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
	No change (%)	4	7	1	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humid	2000 (1000 ha)	448		23,340		0		1,956		872		4,041		125		252		8,320		7,714	
	2030 (1000 ha)	1,163		29,304		0		4,964		1,195		3,697		913		411		9,623		7,391	
	>20% loss (%)	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	5-20% loss (%)	4	41	5	8	0	0	0	2	0	2	0	5	3	35	0	0	3	10	4	35
	No change (%)	4	42	0	8	0	0	2	4	0	2	0	5	0	32	0	0	1	8	1	30
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050 (1000 ha)	1,703		34,368		0		7,353		1,573		3,616		1,351		356		8,686		8,011	
	>20% loss (%)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	1	4	0	1	1	3	0	1	0	0	4	7	2	7	0	0	0	0	0	0
	No change (%)	3	5	0	1	0	2	0	1	0	0	0	4	0	5	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B: Area distribution of farming systems for countries in ECA, and percentage of these areas over different classes of length of growing periods for the years 2000, 2030 and 2050 - continuation

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Mixed irrigated																					
Semi-arid	2000 (1000 ha)	0		0		54		223		17		416		0		3,958		67		0	
	2030 (1000 ha)	0		0		51		225		17		432		0		3,954		73		0	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0
	5-20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
	No change (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050 (1000 ha)	0		0		51		233		17		464		0		3,953		81		0	
	>20% loss (%)	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	No change (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperate	2000 (1000 ha)	0		8		0		30		0		40		0		0		17		8	
	2030 (1000 ha)	0		8		0		15		0		32		0		0		8		7	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	No change (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050 (1000 ha)	0		8		0		8		0		0		0		0		8		7	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	No change (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humid	2000 (1000 ha)	38		22		0		8		0		62		0		0		34		16	
	2030 (1000 ha)	33		25		0		23		0		65		0		0		32		14	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	No change (%)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050 (1000 ha)	33		25		0		23		0		65		0		0		24		14	
	>20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% loss (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	No change (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5-20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B: Area distribution of farming systems for countries in ECA, and percentage of these areas over different classes of length of growing periods for the years 2000, 2030 and 2050 - continuation

	Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Other																				
2000 (1000 ha)	223		167,057		53		3,832		4,648		13,200		327		5,697		14,405		4,446	
2030 (1000 ha)	372		167,572		22		4,479		5,594		13,105		380		5,504		18,564		6,514	
>20% loss (%)	0	0	0	8	0	0	0	0	0	3	0	12	0	0	0	1	0	1	0	2
5-20% loss (%)	0	13	18	63	0	0	0	2	2	5	0	20	3	10	1	2	9	18	3	31
No change (%)	1	14	4	56	0	0	2	4	1	7	0	9	6	13	0	2	2	12	0	29
5-20% gain (%)	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1
>20% gain (%)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
2050 (1000 ha)	372		167,572		22		4,479		5,590		13,103		381		5,504		18,566		6,514	
>20% loss (%)	0	0	0	2	1	7	0	0	0	2	0	1	0	0	0	0	0	0	0	0
5-20% loss (%)	1	2	1	3	4	9	0	0	3	4	9	14	3	6	0	0	0	0	0	0
No change (%)	2	3	1	2	0	2	0	0	0	1	2	7	0	4	0	0	0	0	0	0
5-20% gain (%)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the change in length of growing period classes over the years 2030 and 2050, for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Banana and plantain																					
2000	(ha)	289,363		195,029		535		28,218		118,430		48,522		670,093		2,748		304,277		1,763,315	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	8	0	22	1	20	0	0	2	2	0	0	14	51	0	0	0	0
	5-20% loss (%)	5	23	26	45	70	85	54	75	7	38	28	86	10	46	17	79	27	48	10	59
	No change (%)	77	95	50	74	7	13	13	35	56	77	12	70	53	90	6	25	51	73	41	82
	5-20% gain (%)	0	0	0	0	0	15	1	10	2	16	0	0	1	1	0	4	0	1	0	8
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0
2050	>20% loss (%)	0	0	0	11	19	93	2	57	0	2	4	61	0	1	16	63	0	1	0	2
	5-20% loss (%)	24	88	61	88	7	74	25	57	20	75	39	81	38	92	17	80	70	91	40	95
	No change (%)	12	76	0	39	0	15	3	37	22	66	0	41	6	62	2	18	7	30	3	54
	5-20% gain (%)	0	0	0	0	0	0	1	14	1	13	0	0	1	1	0	5	0	0	0	6
	>20% gain (%)	0	0	0	0	0	0	0	6	0	1	0	0	0	0	1	14	0	0	0	0
Barley																					
2000	(ha)	1		108		54,953		764,034		19,198		0		4		7051		989		92	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	46	5	19	1	2	0	0	0	0	0	0	60	65	0	0	0	0
	5-20% loss (%)	0	0	52	84	77	87	8	47	2	18	0	0	0	75	9	13	25	49	0	42
	No change (%)	100	100	2	27	3	15	49	71	75	84	0	0	25	100	25	26	51	75	51	91
	5-20% gain (%)	0	0	0	3	0	2	3	35	5	21	0	0	0	0	0	1	0	0	0	9
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	95	18	56	2	5	0	0	0	0	0	0	66	71	0	1	0	0
	5-20% loss (%)	0	100	3	90	44	80	8	67	12	64	0	0	75	100	8	28	66	94	16	93
	No change (%)	0	100	2	10	0	3	26	62	34	73	0	0	0	25	1	25	4	34	7	77
	5-20% gain (%)	0	0	0	0	0	0	2	43	0	15	0	0	0	0	0	1	0	0	0	7
	>20% gain (%)	0	0	0	0	0	0	0	8	0	1	0	0	0	0	0	0	0	0	0	0
Beans																					
2000	(ha)	191,971		139,188		2,575		193,983		285		80,369		333,197		19,078		344,910		688,692	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	10	9	22	0	0	7	13	0	4	0	0	6	9	0	0	0	0
	5-20% loss (%)	4	21	25	43	70	82	7	38	31	52	46	92	12	51	27	51	14	36	8	39
	No change (%)	79	96	57	75	7	20	58	77	24	44	4	51	49	87	33	51	63	85	61	84
	5-20% gain (%)	0	0	0	0	0	1	3	29	1	25	0	0	1	1	3	6	0	1	0	10
	>20% gain (%)	0	0	0	0	0	0	0	0	0	9	0	0	0	0	5	7	0	0	0	0
2050	>20% loss (%)	0	0	0	28	19	71	1	6	0	33	5	61	0	1	8	18	0	2	0	2
	5-20% loss (%)	33	85	56	89	29	79	12	63	28	58	39	92	41	93	28	71	43	91	29	94
	No change (%)	15	67	0	44	0	4	30	54	19	25	0	14	6	59	6	34	6	56	4	66
	5-20% gain (%)	0	0	0	0	0	0	1	38	9	17	0	0	1	1	1	5	0	0	0	5
	>20% gain (%)	0	0	0	0	0	0	0	3	0	35	0	0	0	0	6	26	0	0	0	0

Appendix C: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the change in length of growing period class over the years 2030 and 2050 - continuation.

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Cassava																					
2000	(ha)	73,484		1,237,658		0		29,039		51,785		335,664		120,856		4,316		810,474		393,682	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	5	0	0	1	24	0	1	1	4	0	0	4	4	0	0	0	0
	5-20% loss (%)	6	38	19	52	0	0	70	87	11	47	46	93	11	50	72	85	27	48	10	40
	No change (%)	62	94	43	81	0	0	2	22	46	74	6	51	50	89	10	19	52	73	59	79
	5-20% gain (%)	0	0	0	0	0	0	1	7	2	11	0	0	0	0	1	4	0	1	0	12
	>20% gain (%)	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	14	0	0	0	75	0	20	9	71	0	1	5	49	0	5	0	3
	5-20% loss (%)	42	93	49	92	0	0	22	72	20	73	29	89	47	91	46	85	64	90	30	95
	No change (%)	7	58	0	51	0	0	0	31	12	50	0	17	8	53	2	15	6	35	3	63
	5-20% gain (%)	0	0	0	0	0	0	0	8	5	10	0	0	0	0	0	4	0	0	0	7
	>20% gain (%)	0	0	0	0	0	0	0	2	0	21	0	0	0	0	0	0	0	0	0	0
Coffee																					
2000	(ha)	23,110		82,615		5,330		268,736		180,648		179,780		225		2,536		126,322		295,934	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	9	0	8	1	2	0	0	0	2	0	0	70	73	0	0	0	0
	5-20% loss (%)	8	28	26	43	92	100	12	31	2	19	51	96	92	98	7	13	29	51	12	41
	No change (%)	72	92	49	73	0	8	67	74	76	84	2	49	2	8	15	20	48	70	59	78
	5-20% gain (%)	0	0	0	1	0	0	2	14	3	23	0	0	0	0	0	2	1	1	0	11
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	25	0	34	0	6	0	1	1	68	0	0	73	73	0	6	0	1
	5-20% loss (%)	37	90	53	85	66	100	27	65	11	70	32	97	98	100	8	24	69	91	26	94
	No change (%)	10	63	0	47	0	0	26	54	25	73	0	10	0	2	3	19	6	31	4	68
	5-20% gain (%)	0	0	0	0	0	0	2	16	1	14	0	0	0	0	0	2	0	0	0	5
	>20% gain (%)	0	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0	0	0	0	1
Cotton																					
2000	(ha)	2,383		51,903		1,060		46,332		37,806		19,064		0		11,352		1,582		243,050	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	4	0	21	0	2	0	0	0	5	0	0	34	69	0	0	0	0
	5-20% loss (%)	10	26	22	55	79	100	7	21	2	19	56	96	0	0	1	12	9	56	5	31
	No change (%)	74	90	42	78	0	21	78	86	69	78	1	38	0	0	2	26	44	88	68	82
	5-20% gain (%)	0	0	0	0	0	0	1	8	4	30	0	0	0	0	0	0	0	3	0	16
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	32	0	0	1	1
2050	>20% loss (%)	0	0	0	14	0	100	0	7	0	0	7	80	0	0	32	57	0	0	0	2
	5-20% loss (%)	43	90	52	88	0	100	14	43	11	59	19	90	0	0	0	13	31	87	22	94
	No change (%)	10	57	0	48	0	0	50	78	35	60	1	5	0	0	1	7	13	67	3	67
	5-20% gain (%)	0	0	0	0	0	0	0	9	1	28	0	0	0	0	0	5	0	3	0	7
	>20% gain (%)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	29	67	0	0	1	4

Appendix C: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the change in length of growing period class over the years 2030 and 2050 - continuation.

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Groundnuts																					
2000	(ha)	10,991		307,052		0		15,814		16,829		45,116		13,716		1,500,535		125,608		187,442	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	4	0	0	1	2	1	2	4	9	0	0	4	6	0	0	0	0
	5-20% loss (%)	7	32	23	66	0	0	9	54	8	31	36	82	14	57	27	56	32	51	9	43
	No change (%)	68	93	30	77	0	0	42	70	63	73	11	55	43	86	38	58	48	68	57	77
	5-20% gain (%)	0	0	0	0	0	0	2	27	3	18	0	0	0	0	1	11	1	1	0	14
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	21	0	0	0	13	0	10	14	64	0	2	6	17	0	4	0	3
	5-20% loss (%)	33	92	52	85	0	0	13	64	20	67	36	74	48	97	39	78	69	90	36	95
	No change (%)	8	67	0	48	0	0	22	49	28	62	1	24	0	52	7	45	6	31	2	55
	5-20% gain (%)	0	0	0	0	0	0	1	34	1	15	0	0	0	0	0	9	0	0	0	9
	>20% gain (%)	0	0	0	0	0	0	0	7	0	3	0	0	0	0	0	1	0	0	0	0
Maize																					
2000	(ha)	80,409		1,098,548		31,806		1,271,194		1,407,266		175,782		89,597		84,060		1,779,128		678,954	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	2	3	14	0	1	0	0	1	4	0	0	6	8	0	0	0	0
	5-20% loss (%)	5	30	19	44	44	69	4	26	6	38	34	88	9	44	26	47	26	47	4	34
	No change (%)	70	95	55	81	24	52	73	83	58	80	10	62	56	90	44	59	52	73	66	77
	5-20% gain (%)	0	0	0	0	0	1	1	21	2	13	0	0	1	1	2	8	1	1	0	19
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2050	>20% loss (%)	0	0	0	9	13	44	0	7	0	3	9	60	0	0	8	20	0	4	0	1
	5-20% loss (%)	27	89	44	92	56	85	9	48	18	75	40	88	34	89	33	71	63	90	13	93
	No change (%)	11	73	1	56	0	24	45	60	21	66	0	25	10	65	10	48	7	37	6	72
	5-20% gain (%)	0	0	0	0	0	0	0	29	1	12	0	0	1	1	0	7	0	0	0	15
	>20% gain (%)	0	0	0	0	0	0	0	1	0	4	0	0	0	0	1	4	0	0	0	0
Millet																					
2000	(ha)	7,878		39,781		21,968		286,844		87,109		25		5,237		2,371,097		250,106		370,413	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	8	0	5	6	18	0	0	0	0	0	0	1	2	0	0	0	0
	5-20% loss (%)	3	16	28	56	68	71	38	55	3	29	0	0	9	60	23	66	29	47	8	40
	No change (%)	84	97	40	72	27	28	35	46	67	81	100	100	40	91	31	61	51	71	59	80
	5-20% gain (%)	0	0	0	0	0	4	1	9	3	16	0	0	0	0	1	15	1	1	0	12
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	25	5	23	18	27	0	1	0	0	0	1	1	9	0	3	0	3
	5-20% loss (%)	18	70	62	75	63	93	40	49	15	75	0	100	37	94	34	82	70	91	28	95
	No change (%)	30	82	0	38	0	29	24	34	23	69	0	100	5	63	8	49	5	30	3	65
	5-20% gain (%)	0	0	0	0	0	0	0	13	1	14	0	0	0	0	0	14	0	0	0	7
	>20% gain (%)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0

Appendix C: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the change in length of growing period class over the years 2030 and 2050 - continuation.

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Potatoes																					
2000	(ha)	9,175		8,710		4,456		33,050		92,554		48,126		102,124		3,692		36,165		81,247	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	0	0	35	0	0	0	0	0	0	0	0	54	66	0	0	0	0
	5-20% loss (%)	4	34	22	28	63	96	3	20	3	23	19	66	13	42	22	35	29	47	13	54
	No change (%)	66	96	72	78	2	2	75	80	72	78	34	81	57	86	7	10	52	71	46	82
	5-20% gain (%)	0	0	0	0	0	4	1	22	4	19	0	0	1	1	1	3	0	1	0	5
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	0	35	98	0	2	0	0	0	35	0	0	80	86	0	3	0	3
	5-20% loss (%)	30	90	74	100	2	63	13	54	14	67	53	79	32	89	8	14	64	92	40	95
	No change (%)	10	70	0	26	0	4	44	63	32	69	0	47	9	66	1	10	6	36	2	57
	5-20% gain (%)	0	0	0	0	0	0	1	33	1	15	0	0	1	1	0	3	0	0	0	3
	>20% gain (%)	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0
Rice																					
2000	(ha)	13,629		300,546		0		116,271		136,816		1,173,287		3,322		8,117		569,417		72,920	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	4	0	0	3	18	7	17	0	2	0	0	41	47	0	0	0	5
	5-20% loss (%)	8	32	22	38	0	0	57	71	25	43	45	92	9	49	10	24	34	50	15	54
	No change (%)	68	92	60	78	0	0	12	28	29	39	7	54	51	91	10	21	50	65	46	81
	5-20% gain (%)	0	0	0	0	0	0	3	10	7	31	0	0	0	0	0	3	0	1	0	6
	>20% gain (%)	0	0	0	0	0	0	0	6	3	5	0	0	0	0	23	23	0	0	0	0
2050	>20% loss (%)	0	0	0	13	0	0	3	55	2	26	5	61	0	1	25	53	0	8	0	5
	5-20% loss (%)	35	83	48	89	0	0	18	59	20	55	39	90	52	95	6	23	64	87	39	95
	No change (%)	17	65	0	52	0	0	3	30	13	24	0	22	4	48	1	11	6	36	3	58
	5-20% gain (%)	0	0	0	0	0	0	4	22	8	23	0	0	0	0	0	2	0	0	0	2
	>20% gain (%)	0	0	0	0	0	0	0	10	3	41	0	0	0	0	23	60	0	0	0	0
Sorghum																					
2000	(ha)	46,980		93,526		183,944		923,396		120,626		1,323		165,834		4,232,907		639,337		285,763	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	8	4	16	0	2	0	1	1	3	0	0	7	11	0	0	0	0
	5-20% loss (%)	5	19	25	54	74	86	16	48	12	55	33	78	7	43	38	63	26	44	10	50
	No change (%)	81	95	38	74	6	18	49	65	42	80	21	64	56	92	27	48	56	73	50	74
	5-20% gain (%)	0	0	0	1	0	3	2	26	1	7	0	0	1	1	1	6	1	1	0	16
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	23	15	57	2	8	0	10	4	57	0	1	11	32	0	3	0	3
	5-20% loss (%)	17	75	55	86	43	82	17	70	29	80	43	79	36	91	48	71	62	92	38	93
	No change (%)	25	83	1	45	0	6	21	48	14	64	0	37	7	64	4	37	6	38	4	49
	5-20% gain (%)	0	0	0	0	0	0	1	33	0	6	0	0	1	1	0	5	0	1	0	13
	>20% gain (%)	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	1	0	0	0	0

Appendix C: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the change in length of growing period class over the years 2030 and 2050 - continuation.

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Soybeans																					
2000	(ha)	515		25,208		15		13,725		952		11		21,437		2,807		8,783		99,121	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	1	0	0	1	1	0	0	0	36	0	0	25	39	0	0	0	0
	5-20% loss (%)	7	28	39	62	27	100	2	16	15	100	9	100	7	31	3	18	66	86	10	48
	No change (%)	72	93	37	60	0	73	52	82	0	85	0	55	69	93	6	20	13	34	51	77
	5-20% gain (%)	0	0	0	0	0	0	1	38	0	0	0	0	0	0	0	0	0	0	0	16
	>20% gain (%)	0	0	0	0	0	0	0	8	0	0	0	0	0	0	46	50	0	0	0	0
2050	>20% loss (%)	0	0	0	31	0	0	0	11	0	88	18	64	0	0	13	39	0	11	0	3
	5-20% loss (%)	24	85	64	73	100	100	5	33	12	100	27	82	32	87	1	28	87	92	33	92
	No change (%)	15	76	0	36	0	0	30	56	0	6	0	9	13	68	1	4	2	8	5	56
	5-20% gain (%)	0	0	0	0	0	0	1	35	0	0	0	0	0	0	0	0	0	0	0	11
	>20% gain (%)	0	0	0	0	0	0	0	31	0	0	0	0	0	0	50	83	0	0	0	0
Sugar cane																					
2000	(ha)	2,533		26,894		0		11,018		53,260		65,878		883		59,801		14,547		119,464	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	0	0	0	2	12	1	1	1	1	0	0	6	9	0	0	0	0
	5-20% loss (%)	7	33	17	40	0	0	20	34	4	34	22	85	20	67	27	53	30	49	11	49
	No change (%)	67	93	60	83	0	0	48	61	58	77	13	78	33	80	39	56	50	70	51	85
	5-20% gain (%)	0	0	0	0	0	0	3	26	4	15	0	0	0	0	1	10	0	1	0	4
	>20% gain (%)	0	0	0	0	0	0	0	1	1	3	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	8	0	0	4	24	1	5	1	57	0	0	9	22	0	2	0	2
	5-20% loss (%)	40	89	40	92	0	0	18	28	12	76	43	81	54	100	37	74	66	90	35	97
	No change (%)	11	60	0	60	0	0	36	60	13	63	0	50	0	46	6	44	8	34	1	64
	5-20% gain (%)	0	0	0	0	0	0	1	34	4	9	0	0	0	0	0	9	0	0	0	1
	>20% gain (%)	0	0	0	0	0	0	0	9	1	16	0	0	0	0	0	1	0	0	0	0
Sweet potatoes																					
2000	(ha)	103,393		61,290		0		94,323		57,502		85,851		172,204		55,484		420,649		541,741	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	1	0	0	0	0	0	0	7	11	0	0	3	6	0	0	0	0
	5-20% loss (%)	4	34	36	51	0	0	4	39	6	30	41	73	10	44	31	56	24	36	9	44
	No change (%)	66	96	48	64	0	0	60	77	66	77	16	49	55	90	37	55	63	76	56	81
	5-20% gain (%)	0	0	0	0	0	0	1	23	3	17	0	0	1	1	1	10	0	1	0	11
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	17	0	0	0	3	0	5	17	59	0	1	6	20	0	3	0	3
	5-20% loss (%)	32	92	58	83	0	0	17	79	16	69	41	69	36	92	42	73	53	91	29	94
	No change (%)	8	68	0	42	0	0	17	49	26	69	0	24	7	64	7	42	6	46	3	66
	5-20% gain (%)	0	0	0	0	0	0	0	30	0	14	0	0	1	1	0	9	0	1	0	4
	>20% gain (%)	0	0	0	0	0	0	0	4	0	1	0	0	0	0	0	0	0	0	0	0

Appendix C: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the change in length of growing period class over the years 2030 and 2050 - continuation.

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Wheat																					
2000	(ha)	0		5		0		183,306		46,112		2,174		0		12,468		23,563		2,429	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
2030	>20% loss (%)	0	0	0	0	0	0	0	4	0	0	0	0	0	0	77	99	0	0	0	0
	5-20% loss (%)	0	0	0	0	0	0	5	43	0	21	39	100	0	0	0	18	28	49	10	70
	No change (%)	0	0	100	100	0	0	55	76	77	95	0	61	0	0	0	5	51	71	29	86
	5-20% gain (%)	0	0	0	0	0	0	2	36	1	5	0	0	0	0	0	0	0	2	0	5
	>20% gain (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2050	>20% loss (%)	0	0	0	0	0	0	3	5	0	0	0	81	0	0	95	99	0	2	0	1
	5-20% loss (%)	0	0	0	100	0	0	5	67	28	66	19	97	0	0	0	5	48	96	56	97
	No change (%)	0	0	0	100	0	0	27	63	33	66	0	13	0	0	0	0	2	52	2	42
	5-20% gain (%)	0	0	0	0	0	0	1	49	1	4	0	0	0	0	0	0	0	0	0	2
	>20% gain (%)	0	0	0	0	0	0	0	6	0	2	0	0	0	0	0	0	0	0	0	0

Appendix D: The number of (predicted) livestock for countries in ECA, and the relative distribution of this livestock (%) over the change in length of growing period class for the years 2000, 2030 and 2050, for the ECHam4 and the HadCM3 GCM for scenarios A1F1 and B1.

		Burundi		DRC		Eritrea		Ethiopia		Kenya		Madagascar		Rwanda		Sudan		Tanzania		Uganda	
Cattle	2000	316,506		830,608		2,122,228		32,952,708		13,895,365		10,276,710		718,363		36,943,276		17,317,922		5,939,250	
	2030	319,996		1,600,917		2,672,859		46,869,488		13,015,093		15,683,707		822,738		72,952,672		19,888,990		11,849,631	
	>20% loss (%)	0	0	0	2	20	45	0	1	0	1	2	12	0	0	11	16	0	0	0	0
	5-20% loss (%)	6	26	39	61	50	62	10	39	7	32	51	91	12	51	26	45	22	35	10	45
	No change (%)	74	94	39	61	5	15	58	71	59	73	4	36	49	87	39	51	64	77	54	81
	5-20% gain (%)	0	0	0	0	0	2	2	18	5	18	0	0	0	0	1	9	1	2	0	10
	>20% gain (%)	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0
	2050	359,665		2,013,643		2,620,650		48,970,284		12,369,902		17,943,082		938,771		98,141,856		20,348,820		16,667,636	
	>20% loss (%)	0	0	0	29	43	81	1	7	0	9	18	63	0	1	16	26	0	2	0	3
	5-20% loss (%)	31	84	65	76	19	51	18	63	19	66	36	80	40	95	33	65	55	90	31	95
	No change (%)	16	69	6	26	0	4	28	58	20	64	1	11	3	59	8	40	8	44	2	63
	5-20% gain (%)	0	0	0	0	0	2	2	22	3	15	0	0	0	0	0	9	0	1	0	5
	>20% gain (%)	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	1	0	0	0	0
Goat	2000	745,313		4,133,738		1,683,044		8,575,345		9,540,009		1,341,010		755,204		38,379,556		11,621,572		6,320,805	
	2030	1,567,645		8,446,144		1,725,523		10,792,430		10,979,510		2,738,179		1,367,455		48,999,116		15,606,662		14,153,857	
	>20% loss (%)	0	0	0	1	20	45	1	2	1	2	11	64	0	0	11	15	0	0	0	0
	5-20% loss (%)	6	25	41	61	50	63	18	48	10	31	27	82	9	47	23	43	23	38	11	43
	No change (%)	75	94	39	59	5	15	47	64	51	56	2	9	53	90	42	55	61	76	55	82
	5-20% gain (%)	0	0	0	0	0	2	3	17	11	30	0	0	0	0	1	9	1	2	1	7
	>20% gain (%)	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	1
	2050	2,063,576		10,952,793		1,600,355		9,660,737		10,637,557		3,195,466		1,761,363		53,009,076		16,137,359		21,194,676	
	>20% loss (%)	0	0	0	29	43	82	2	13	2	10	35	80	0	0	15	24	0	3	0	3
	5-20% loss (%)	31	84	66	76	18	51	24	61	19	52	20	59	37	93	32	68	57	88	33	93
	No change (%)	16	69	5	29	0	4	22	54	27	49	0	5	6	63	8	43	9	42	2	62
	5-20% gain (%)	0	0	0	0	0	2	2	20	6	25	0	0	0	0	0	9	0	1	0	4
	>20% gain (%)	0	0	0	0	0	0	0	1	2	6	0	0	0	0	0	0	0	0	1	1
Sheep	2000	214,992		926,714		1,552,459		10,931,148		8,397,134		782,565		252,640		45,917,892		3,494,112		1,086,911	
	2030	546,087		1,973,694		1,580,664		13,867,478		9,372,741		1,603,093		504,544		57,270,480		5,333,780		2,403,410	
	>20% loss	0	0	0	2	21	46	0	2	1	2	10	73	0	0	11	15	0	0	0	0
	5-20% loss	6	24	38	58	50	62	11	43	7	26	22	81	7	37	26	45	20	37	11	47
	No change	75	94	40	62	4	15	54	70	59	63	1	9	62	92	40	52	62	77	52	83
	5-20% gain	0	0	0	0	0	2	2	23	9	26	0	0	1	1	1	8	1	3	1	7
	>20% gain	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0
	2050	718,838		2,559,741		1,466,279		13,000,947		9,075,024		1,870,816		649,810		61,971,652		5,514,001		3,592,606	
	>20% loss	0	0	0	34	44	82	1	9	1	6	34	86	0	0	15	25	0	2	0	5
	5-20% loss	31	83	60	69	18	50	16	63	16	56	14	59	26	91	35	67	54	89	36	94
	No change	16	69	6	31	0	4	25	53	27	56	0	6	8	73	8	40	8	45	1	60
	5-20% gain	0	0	0	0	0	2	2	29	5	22	0	0	1	1	0	8	0	2	0	3
	>20% gain	0	0	0	0	0	0	0	1	2	5	0	0	0	0	0	0	0	0	0	1

Appendix E: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the development domains.

	Burundi	DRC	Eritrea	Ethiopia	Kenya	Madagascar	Rwanda	Sudan	Tanzania	Uganda
Banana and plantain										
2000 (ha)	289,363	195,029	535	28,218	118,430	48,522	670,093	2,748	304,277	1,763,315
HHH (%)	11	5	0	0	7	0	18	0	1	13
HHL (%)	4	19	0	0	1	7	0	0	1	3
HLH (%)	76	11	0	4	19	0	68	0	4	18
HLL (%)	9	61	0	2	10	12	1	1	13	12
LHH (%)	0	0	16	3	5	2	0	1	1	5
LHL (%)	0	0	6	35	10	25	0	17	6	6
LLH (%)	0	5	32	6	15	2	12	0	4	18
LLL (%)	0	0	46	51	33	51	2	80	70	26
Barley										
2000 (ha)	1	108	54,953	764,034	19,198	0	4	7,051	989	92
HHH (%)	0	0	0	1	3	0	0	0	1	6
HHL (%)	0	15	0	1	1	67	0	0	1	0
HLH (%)	78	0	0	5	7	0	22	0	4	28
HLL (%)	22	76	0	3	3	0	17	0	8	49
LHH (%)	0	0	2	8	10	0	0	0	2	3
LHL (%)	0	1	11	3	21	0	0	6	6	0
LLH (%)	0	0	10	56	19	0	33	0	6	6
LLL (%)	0	6	76	24	36	33	28	94	73	8
Beans										
2000 (ha)	191,971	139,188	2,575	193,983	285	80,369	333,197	19,078	344,910	688,692
HHH (%)	29	3	0	3	5	0	19	0	2	24
HHL (%)	4	32	0	1	0	5	0	2	1	11
HLH (%)	62	7	0	11	0	0	72	0	11	29
HLL (%)	5	57	0	5	0	5	0	6	40	19
LHH (%)	0	0	1	8	10	1	0	0	0	1
LHL (%)	0	0	16	5	20	45	0	14	3	3
LLH (%)	0	1	15	44	15	1	8	0	8	4
LLL (%)	0	0	68	23	50	43	0	78	34	8

Note: “H” and “L” refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Appendix E: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the development domains, continuation.

	Burundi	DRC	Eritrea	Ethiopia	Kenya	Madagascar	Rwanda	Sudan	Tanzania	Uganda
Cassava										
2000 (ha)	73,484	1,237,658	0	29,039	51,785	335,664	120,856	4,316	810,474	393,682
HHH (%)	23	1	0	0	7	1	21	0	2	28
HHL (%)	5	22	0	0	1	2	0	5	1	13
HLH (%)	66	1	0	0	14	0	65	0	9	26
HLL (%)	6	75	0	0	7	4	0	5	28	22
LHH (%)	0	0	0	0	3	1	0	1	0	1
LHL (%)	0	1	0	45	15	20	0	20	5	2
LLH (%)	0	0	0	3	7	1	12	0	4	3
LLL (%)	0	0	0	52	46	72	1	69	51	5
Coffee										
2000 (ha)	23,110	82,615	5,330	268,736	180,648	179,780	225	2,536	126,322	295,934
HHH (%)	14	1	0	2	10	0	0	0	0	20
HHL (%)	9	21	0	0	3	3	0	1	1	7
HLH (%)	72	2	0	17	6	0	88	0	3	22
HLL (%)	5	74	0	12	2	2	0	1	9	15
LHH (%)	0	0	0	3	20	0	0	0	0	3
LHL (%)	0	0	8	5	11	38	0	2	6	3
LLH (%)	0	0	25	18	27	0	11	0	7	8
LLL (%)	0	1	67	43	20	56	1	97	74	22
Cotton										
2000 (ha)	2,383	51,903	1,060	46,332	37,806	19,064	0	11,352	1,582	243,050
HHH (%)	25	4	0	0	1	0	0	0	0	43
HHL (%)	14	17	0	1	1	0	0	1	0	10
HLH (%)	50	9	0	4	6	0	100	0	18	23
HLL (%)	12	70	0	24	5	0	0	0	23	20
LHH (%)	0	0	0	0	7	1	0	0	4	1
LHL (%)	0	0	32	3	13	56	0	11	4	0
LLH (%)	0	0	68	0	32	0	0	0	29	2
LLL (%)	0	0	0	69	35	43	0	88	22	1

Note: "H" and "L" refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Appendix E: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the development domains, continuation.

	Burundi	DRC	Eritrea	Ethiopia	Kenya	Madagascar	Rwanda	Sudan	Tanzania	Uganda
Groundnuts										
2000 (ha)	10,991	307,052	0	15,814	16,829	45,116	13,716	1,500,535	125,608	187,442
HHH (%)	31	2	0	0	5	0	15	0	1	23
HHL (%)	4	24	0	0	1	4	0	0	1	19
HLH (%)	58	1	0	1	12	1	72	0	3	24
HLL (%)	6	70	0	0	6	11	0	1	13	20
LHH (%)	0	0	0	6	9	3	0	1	0	1
LHL (%)	0	0	0	14	13	32	0	20	6	3
LLH (%)	0	0	0	42	21	6	13	0	3	3
LLL (%)	0	3	0	36	33	44	0	78	74	6
Maize										
2000 (ha)	80,409	1,098,548	31,806	1,271,194	1,407,266	175,782	89,597	84,060	1,779,128	678,954
HHH (%)	36	1	0	2	17	1	19	0	1	22
HHL (%)	2	27	0	2	1	5	0	1	1	5
HLH (%)	59	2	0	9	11	1	73	0	6	20
HLL (%)	3	68	0	12	6	11	0	1	13	25
LHH (%)	0	0	1	9	5	1	0	1	1	0
LHL (%)	0	0	7	6	13	19	0	14	6	4
LLH (%)	0	0	5	35	10	4	7	0	4	2
LLL (%)	0	1	87	26	36	59	1	84	67	21
Millet										
2000 (ha)	7,878	39,781	21,968	286,844	87,109	25	5,237	2,371,097	250,106	370,413
HHH (%)	41	10	0	2	7	0	16	0	0	27
HHL (%)	8	19	0	0	1	0	0	0	0	15
HLH (%)	48	8	0	4	18	0	65	0	3	26
HLL (%)	3	61	0	1	11	100	1	0	10	24
LHH (%)	0	0	4	12	7	0	0	0	0	1
LHL (%)	0	0	8	10	6	0	0	17	8	1
LLH (%)	0	0	5	28	23	0	16	0	6	1
LLL (%)	0	1	83	41	27	0	2	83	72	4

Note: "H" and "L" refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Appendix E: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the development domains, continuation.

	Burundi	DRC	Eritrea	Ethiopia	Kenya	Madagascar	Rwanda	Sudan	Tanzania	Uganda
Potatoes										
2000 (ha)	9,175	8,710	4,456	33,050	92,554	48,126	102,124	3,692	36,165	81,247
HHH (%)	30	4	0	2	6	0	18	0	1	13
HHL (%)	2	3	0	1	1	10	0	1	1	8
HLH (%)	67	27	0	21	17	2	79	0	4	31
HLL (%)	1	65	0	8	9	31	0	2	10	22
LHH (%)	0	0	5	9	7	0	0	0	1	2
LHL (%)	0	0	13	5	11	5	0	25	6	4
LLH (%)	0	1	6	34	18	4	3	0	6	7
LLL (%)	0	0	76	19	32	48	0	71	72	14
Rice										
2000 (ha)	13,629	300,546	0	116,271	136,816	1,173,287	3,322	8,117	569,417	72,920
HHH (%)	24	0	0	0	5	1	33	0	1	20
HHL (%)	4	35	0	0	0	6	0	1	1	13
HLH (%)	68	4	0	0	1	0	60	0	6	21
HLL (%)	4	61	0	0	0	4	0	0	23	21
LHH (%)	0	0	0	0	7	3	0	1	0	2
LHL (%)	0	0	0	34	17	28	0	13	6	3
LLH (%)	0	0	0	2	5	2	7	0	5	6
LLL (%)	0	0	0	64	65	57	0	85	57	13
Sorghum										
2000 (ha)	46,980	93,526	183,944	923,396	120,626	1,323	165,834	4,232,907	639,337	285,763
HHH (%)	35	4	0	0	4	1	20	0	2	17
HHL (%)	5	18	0	0	0	5	0	0	0	17
HLH (%)	58	6	0	2	8	1	75	0	11	28
HLL (%)	2	70	0	4	5	10	0	0	15	16
LHH (%)	0	0	3	8	6	2	0	1	1	0
LHL (%)	0	0	10	5	18	28	0	32	8	12
LLH (%)	0	0	6	42	8	3	6	1	5	2
LLL (%)	0	1	81	39	50	51	0	66	58	7

Note: "H" and "L" refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Appendix E: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the development domains, continuation.

	Burundi	DRC	Eritrea	Ethiopia	Kenya	Madagascar	Rwanda	Sudan	Tanzania	Uganda
Soybeans										
2000 (ha)	515	25,208	15	13,725	952	11	21,437	2,807	8,783	99,121
HHH (%)	4	5	0	0	0	0	19	0	0	23
HHL (%)	1	13	0	0	0	0	0	3	1	16
HLH (%)	92	7	0	2	0	0	77	0	2	27
HLL (%)	2	75	0	6	0	0	0	0	52	19
LHH (%)	0	0	0	2	0	0	0	0	0	0
LHL (%)	0	0	0	7	1	63	0	13	3	3
LLH (%)	0	0	0	6	0	0	3	0	1	3
LLL (%)	0	0	100	77	99	37	0	83	41	9
Sugarcane										
2000 (ha)	2,533	26,894	0	11,018	53,260	65,878	883	59,801	14,547	119,464
HHH (%)	16	3	0	0	8	0	0	0	1	17
HHL (%)	5	23	0	0	3	10	0	0	1	18
HLH (%)	73	8	0	0	10	0	94	0	4	16
HLL (%)	7	64	0	1	5	14	0	1	17	23
LHH (%)	0	0	0	2	12	1	0	1	2	3
LHL (%)	0	0	0	40	11	26	0	17	5	7
LLH (%)	0	2	0	6	19	2	6	1	9	8
LLL (%)	0	0	0	51	33	47	0	80	62	8
Sweet potatoes										
2000 (ha)	103,393	61,290	0	94,323	57,502	85,851	172,204	55,484	420,649	541,741
HHH (%)	29	4	0	4	4	0	20	0	3	27
HHL (%)	3	24	0	3	1	6	0	1	1	10
HLH (%)	65	10	0	20	13	1	74	0	11	20
HLL (%)	4	62	0	20	8	15	0	5	18	24
LHH (%)	0	0	0	4	9	1	0	1	0	2
LHL (%)	0	0	0	2	11	25	0	20	6	3
LLH (%)	0	1	0	32	26	3	6	0	8	4
LLL (%)	0	0	0	14	29	50	0	73	54	9

Note: “H” and “L” refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Appendix E: The harvested area (ha) of crop commodities for countries in ECA, and the relative distribution of these crops (%) over the development domains, continuation.

	Burundi	DRC	Eritrea	Ethiopia	Kenya	Madagascar	Rwanda	Sudan	Tanzania	Uganda
Wheat										
2000 (ha)	0	5	0	183,306	46,112	2,174	0	12,468	23,563	2,429
HHH (%)	0	0	0	1	14	8	0	0	0	10
HHL (%)	0	0	0	0	10	2	0	0	0	0
HLH (%)	0	14	0	2	38	3	0	0	1	23
HLL (%)	0	86	0	1	10	3	0	0	6	29
LHH (%)	0	0	0	10	4	13	0	0	1	0
LHL (%)	0	0	0	7	3	29	0	13	12	8
LLH (%)	0	0	0	59	5	0	0	0	3	6
LLL (%)	0	0	0	20	16	42	0	87	78	23

Note: "H" and "L" refer to the following characteristics: agricultural potential, market access, and population density, in that order.

Appendix F: The total number of animals for countries in ECA, and the relative distribution of these animals (%) over the development domains.

	Burundi	DRC	Eritrea	Ethiopia	Kenya	Madagascar	Rwanda	Sudan	Tanzania	Uganda
Cattle										
2000 (ha)	316,506	830,608	2,122,228	32,952,708	13,895,365	10,276,710	718,363	36,943,276	17,317,922	5,939,250
HHH (%)	19	3	0	3	13	0	13	0	17	18
HHL (%)	5	22	0	1	2	1	0	1	1	8
HLH (%)	67	7	0	13	14	0	72	0	8	28
HLL (%)	9	60	0	13	6	1	3	3	1	19
LHH (%)	0	0	2	5	6	1	0	1	61	2
LHL (%)	0	0	13	5	8	24	0	17	6	3
LLH (%)	0	2	5	25	9	1	9	1	6	7
LLL (%)	0	5	80	36	40	71	3	76	1	16
Goat										
2000 (ha)	745,313	4,133,738	1,683,044	8,575,345	9,540,009	1,341,010	755,204	38,379,556	11,621,572	6,320,805
HHH (%)	20	2	0	1	5	0	15	0	19	22
HHL (%)	5	22	0	1	1	0	0	2	1	8
HLH (%)	66	5	0	7	7	0	71	0	6	35
HLL (%)	10	68	0	6	5	0	1	5	1	15
LHH (%)	0	0	2	5	4	1	0	1	62	2
LHL (%)	0	0	13	6	8	29	0	15	6	1
LLH (%)	0	0	5	24	8	0	12	1	5	7
LLL (%)	0	3	80	50	61	70	2	76	1	10
Sheep										
2000 (ha)	214,992	926,714	1,552,459	10,931,148	8,397,134	782,565	252,640	45,917,892	3,494,112	1,086,911
HHH (%)	21	2	0	2	5	0	13	0	15	16
HHL (%)	5	19	0	1	2	0	0	2	1	7
HLH (%)	65	6	0	10	10	0	85	0	4	26
HLL (%)	9	66	0	11	6	0	0	4	0	16
LHH (%)	0	0	2	5	4	1	0	1	67	7
LHL (%)	0	1	13	5	7	24	0	15	6	3
LLH (%)	0	1	6	32	8	0	2	1	6	13
LLL (%)	0	5	79	34	59	75	0	76	1	12

Note: "H" and "L" refer to the following characteristics: agricultural potential, market access, and population density, in that order.

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