Managing current and future climate induced risk in Eastern and Central African Agriculture

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ABSTRACT

Agriculture, the mainstay of economies of all countries in Eastern and Central Africa, continue to remain underdeveloped with inadequate adoption of yield-enhancing technologies, inefficient with low levels of productivity and uncompetitive in a rapidly globalizing world. Farmers continue to prefer use of conventional techniques involving low level of investments over improved technologies that led to green revolution in other regions of the world. One of the main reasons for the low levels of adoption of improved technologies is that agriculture in the region is predominantly rainfed and hence highly vulnerable to uncertain and erratic distribution of rainfall. Rainfall during the crop season, especially in the semi-arid areas, varies from about one third to two and half times the normal amounts creating vastly different seasons with different possibilities. Analysis of long-term historical climatic data indicates that the region experiences cycles of wet and dry periods that are closely linked to cycles in ENSO phenomenon. The entire region, with the exception of Sudan, records above normal rainfall during El Nino years. An increasing trend in temperature is noticed in all the months and in the annual mean minimum and maximum temperatures. The observed rate of increase in temperature compares well with those reported by IPCC in its fourth assessment report. According to IPCC the region will be warmer by about 3.2^{0}C and will receive 11% more rainfall by end of the century. Though there are problems in predicting accurately where, when and by how much climate changes, there is general consensus that the rainfall will be more variable with increased frequency of occurrence of extreme vents. The current variability and projected changes will have significant negative impacts on agriculture through changes in the growing environment and in other parameters such as nutrient and water availability on which crop production depends. Several available soil, water and crop management technologies have the potential to mitigate the negative impacts of climate variability and change but their adoption by smallholder farmers is very low, mainly due climate induced risk and uncertainty over returns on investment. The paper presents some of the available options that help in preparing for and managing climate risks. It highlights the potential benefits from use of seasonal climate forecast information in planning farm operations and suggests some simple, inexpensive and efficient technologies that involve very low levels of investment and risk. In general, research community from the region paid very little attention to climate induced risk in agriculture which needs to be corrected to address the threats from climate change effectively.

1. Introduction

Agriculture is, and will remain for the foreseeable future, the most important sector in the economies of almost all countries in Eastern and Central Africa (ECA). It constitutes nearly 40% of the region's GDP and more importantly is the main or only livelihood for nearly 80% of the region's population (IFPRI, 2004). Despite its importance, agriculture in the region remains underdeveloped with inadequate adoption of yield-enhancing technologies, inefficient with low levels of productivity and uncompetitive in a rapidly globalizing world. The poor performance of African agriculture is even starker when compared with the progress achieved by countries in Asia and Latin America in increasing food production. While developing countries in those regions reaped good benefits from improved technologies, most countries in the region failed to benefit from the same. Sub-Saharan Africa is the only region in the world in which the average per capita food production has stagnated and is still at levels reported two decades ago (FAO, 2004). The growth rate for cereals grain yield is about 1%, much below the population growth rate of 3% (UN, 2001). As a result the per capita cereals production has decreased from 150 to 130 kg/person, whereas Asia and Latin America have recorded an increase from about 200–250 kg/person (FAO, 2001). Between 2005 and 2008 average yields of maize, main cereal grown over 25 million hectares in Africa, were estimated at 3.8 t/ha in Brazil, 3.1 t/ha in Mexico, 2.5 t/ha in the Philippines, and 3.9 t/ha in Thailand, compared to 1.4 t/ha in Sub-Saharan Africa (SSA). The situation is not very different for other crops. The continuous practice of low input subsistence agriculture with unsustainable management practices is leading to decline in soil fertility and organic matter, resulting in severe erosion of the productive potential of the resource base. Fertilizer use by African farmers is extremely low by international standards – around 8 kg/ha, compared to a global average of 100 kg/ha. 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).

Lack of agricultural development in Africa has been the subject of many studies, assessments and reports from as early as 1938. As pointed out by Easterly (2009) most of them highlight the same problems and suggest even the same solutions. He also draws attention to the fact that technological solutions to major problems faced by African agriculture are well known and have been around for several decades. For example, soil fertility is a never-ending problem with which the farmer will always have to contend. A number of practical and feasible technologies that include chemical, biological and cultural interventions for improving soil fertility are available but the same are rarely used by subsistence smallholder farmers. The reasons for farmers not investing on fertilizer are many. Among the major limitations are high cost of fertilizers, limited access, and low profit incentive. Considering that African agriculture is primarily rainfed and is entirely dependent on rainfall that is both seasonal and highly variable, we argue that low profit incentive stemming from uncertainty and risk associated with variable climatic conditions is the primary reason for low adoption of fertility enhancing technologies. The same is true with the adoption of improved varieties, soil and water conservation measures and several other productivity enhancing technologies.

Rainfed agriculture is one of the most vulnerable sectors to variability in climatic conditions that occurs at many temporal scales, from seasons to years to decades and beyond. While the amount and distribution of rainfall has a direct impact on the productivity of agriculture, its variability contributes to uncertainty in the expected performance of farm production and to the rates of return that farmers receive from investing in innovative farming practices (van de Steeg et al., 2009). Overlaid on this challenging scenario is the accepted prediction that, whatever happens to future greenhouse gas emissions, we are now locked into global warming and inevitable changes to rainfall patterns which are likely to exacerbate existing rainfall variability in many parts of Africa and further increase the frequency of climatic extremes. Though uncertainty prevails over the precise nature and extent of these changes, most climate change projections for the region indicate an increase in temperatures by about 2.5^0C to 3.0^0C accompanied by modest and seasonally variable increases in precipitation (5–10 %) by mid-century (IPCC, 2007). These apparently small changes in the climate can have big implications for agriculture.

Eastern and Central Africa (ECA) is one of the most vulnerable regions to climate variability and change due to its predominantly semi-arid to arid climate, degraded soils, extreme poverty and lack of infrastructure (Fischer et al., 2005; IPCC 2007). The region experiences prolonged and highly destructive droughts covering large areas at least once every decade and more localised events more frequently. The region recorded severe droughts and/or famines in 1973-74, 1984-85, 1987, 1992-94, 1999-2000, 2005-2006 and more recently in 2010-11. According to UNDP (2006), a single drought event in a 12-year period will lower GDP by 7%–10% and increase poverty by 12%–14%. Extreme events, including floods and droughts, are becoming increasingly frequent and severe (IPCC 2007). The negative impacts of climate are not limited to the years with extreme climatic conditions. Even with normal rainfall, the countries in the region do not produce enough food to meet their people's needs. Left unmanaged, these impacts can have far-reaching consequences on the local food security, economy, and poverty.

The objective of this paper is to provide a brief account of climate induced risk in agriculture and discuss available options to mitigate risks while capitalizing on opportunities associated with variable climate in ECA region. It focuses on prospects to cope adequately with current climatic variability in the rain-fed farming systems which while serving the immediate needs and requirements of smallholder farmers in the region, will serve as a stepping stone to adapt to challenges posed by climate change. Much of the information in this paper is sourced from studies conducted through projects funded by ASARECA and Climate Change Adaptation in Africa (CCAA) program of IDRC/DFID. In the section following this introduction, the paper provides a brief review of the climate of the region with special focus on observed trends and variability followed by projected changes in the climate due to global warming from increased concentration of greenhouse gases in the atmosphere. In the third section, it explores the impacts of current and projected changes in climate on agriculture. The fourth section describes with evidence potential management strategies that can be employed to reduce vulnerability of agricultural systems to climate induced uncertainties through better preparedness, tactical management and lasting recovery. Though options like use of heat and drought tolerant varieties, soil and water conservation practices including irrigation, agroforestry, conservation agriculture and other sustainable management practices are widely suggested in the strategies to adapt agriculture to climate change, they are not covered in this paper. These practices are extremely useful in buffering the climate induced stresses and extensive literature is available on the effectiveness of these practices both in the region and globally. It focuses more on how risk associated with variable climate is constraining adoption of these technologies and what options are available to reduce this risk and promote use of technologies. Considering fairly good reliability of seasonal climate forecasts, potential value of this information in planning farm operations and applicability to other countries in the region, a more detailed account about the usefulness of seasonal climate forecasts is included. This is also one of the major interventions developed, tested and promoted under the projects supported by ASARECA-CGS. The last two sections of this paper draws conclusions from the work being reported and provide recommendations for further strengthening the research on climate variability within ASARECA and its partner instituions.

2. Climate of the region:

The climate over Equatorial Eastern Africa is considered as one of the most complex due to large scale tropical controls that include several major convergence zones superimposed on regional factors such as lakes, topography and maritime influences (Nicholson, 1996). Eastern Africa exhibits high seasonal rainfall variability (Figure 1) ranging from unimodal, bimodal and trimodal rainfall distributions (Ogallo, 1989 and Indege et al., 2000). However, much of the region experiences bimodal pattern of rainfall near the Equator and tends to a unimodal system with distance from the Equator (Conway et al., 2005), with wet seasons from March to May and October to December.

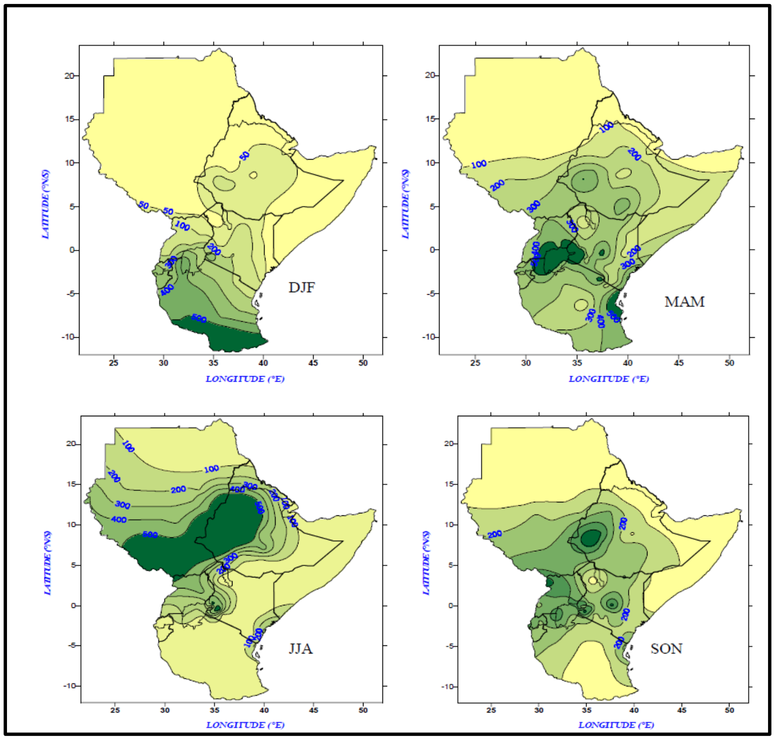

Figure 1. Seasonal rainfall distribution in Eastern Africa (Ogallo, 1989)

Highlands of central Kenya, southern and western Tanzania, south-western Ethiopia and much of Uganda receive rainfall of more than 800 mm, with the northern and eastern parts of Kenya and east central Tanzania, which are semi-arid, receiving less. In the December to February season, the rainfall is concentrated over the lake regions and most parts of Tanzania. March to May season is the main rainfall season and accounts nearly 42% of the total regional annual rainfall, with the highest intensity observed near the water bodies of the Indian Ocean, Lake Victoria and the East African highlands (Indeje et al., 2000). The June to August rainfall season which accounts for about 15% of the total regional annual rainfall is confined to the western highlands of Kenya and Ethiopia, the coastal areas and most parts of Uganda. The September to November rainfall season contributes about 25% of the total regional annual rainfall and is well distributed in the whole of East African region.

Within these seasons, altitude and other localized variables produce distinctive regional climates characterised by widely diverse climates ranging from desert to forest over relatively small areas, changing within tens of kilometres. More than a third of ECA region total land area of 8.1 million km^2 is covered by semi-arid and sub-humid agro-ecologies where variability and change in climate are going to have a profound effect on the future of agriculture (Figure 2).

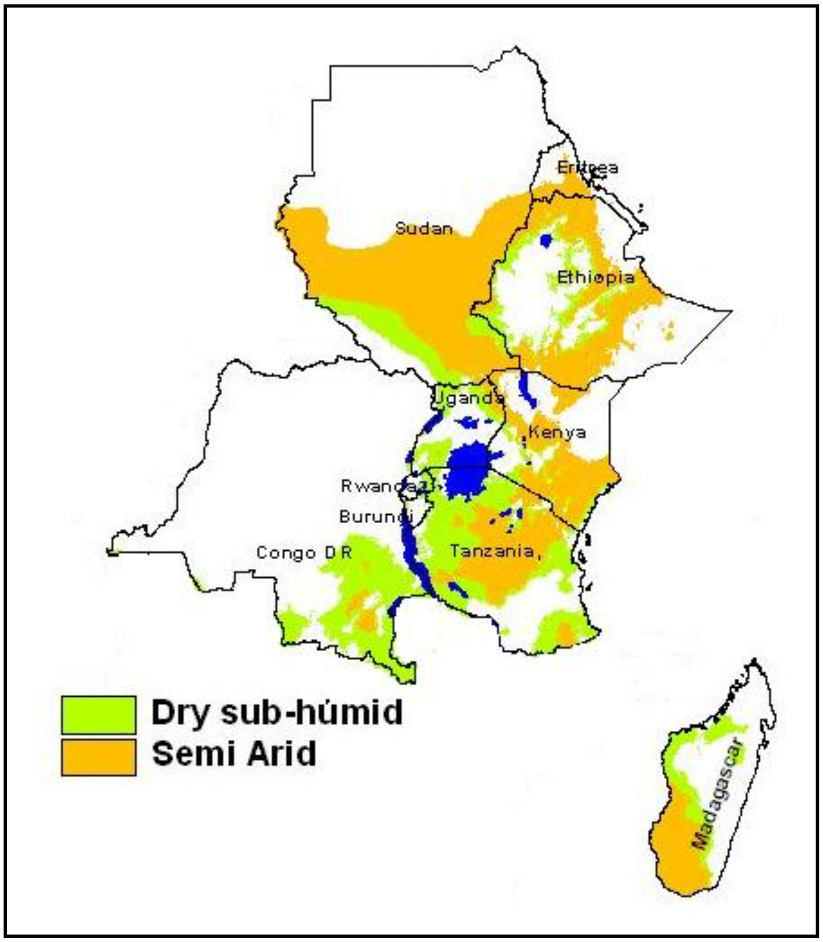

Figure 2: Distribution of drylands in Eastern and central Africa. (Areas with an aridity index of 0.2 to 0.5 are designated as semi-arid and those with an aridity index of 0.5 to 0.65 as dry sub-humid)

2.1 Variability and trends in climate of ECA region:

Rainfall across the region is highly variable both within and between seasons and the variability increases disproportionately as one move from sub-humid to semi-arid regions (Figure 3). Within semi-arid tropics, rainfall during a crop season varies from about one third to two and half times the normal amounts and this variability in rainfall is the primary source of uncertainty and the main cause for the large fluctuations in farmers' income. For example, available records at Melkasa in Ethiopia indicate that annual rainfall varied from 550 mm in 2002 to 1300 mm in 1977 and at Katumani in Kenya rainfall varied from 350 mm in 1987 to 1250 mm in 1963. Optimizing farm management under these highly variable conditions is a major challenge since management practices that are appropriate for average to above average seasons may perform poorly or even fail in below normal seasons.

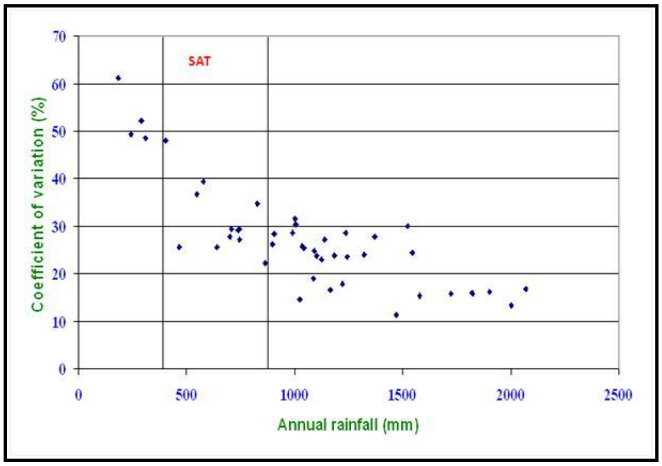

Figure 3: Long-term mean rainfall totals (mm) and the variability for different locations in ECA

Historical trends in rainfall over Eastern Africa indicate cycles of wet and dry periods and the trends in temporal variability of rainfall at most locations are very similar. Rainfall showed mostly positive anomalies during 1960s followed by negative anomalies during the 1970s (Figure 4). After 1970s, the fluctuations in rainfall are dominated by short period cycles of about five years duration that normally coincide with the swings in the El Niño/La Niña-Southern Oscillation (ENSO). Several studies that analysed rainfall variability in Eastern Africa have concluded that the variability in rainfall is closely associated with ENSO phenomenon and sea surface temperatures with a time scale of variability of 5 to 6 years (Nicholson, 1996, Schreck and Semazzi, 2004, Indeje et al. 2000). El Nino is associated with above-normal rainfall amounts during the short rains throughout the entire region, except for Sudan. This relationship between rainfall and ENSO phenomenon makes the rainfall in the region more predictable. No discernable increasing or decreasing trend either in the annual or seasonal rainfall is observable. The proportion of negative anomalies ranged between 49% and 59% for the stations we have data, indicating fairly equal distribution of positive and negative anomalies (Rao et al., 2011).

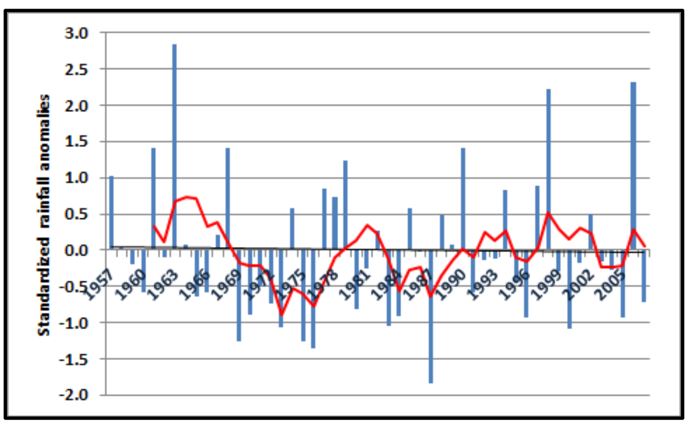

Figure 4: Standardized annual rainfall anomalies at Katumani.

However, a general increasing trend in both minimum and maximum temperatures especially from about 1990 onwards is noticed in most months and in mean annual temperature (Figure 5) and the rate of increases are similar to the ones reported by IPCC (IPCC, 2007). This supports that the region is warming along the lines predicted globally. Unfortunately, the analysis is limited by availability of good quality data. There are very few meteorological stations in the region with good records of long-term temperature data.

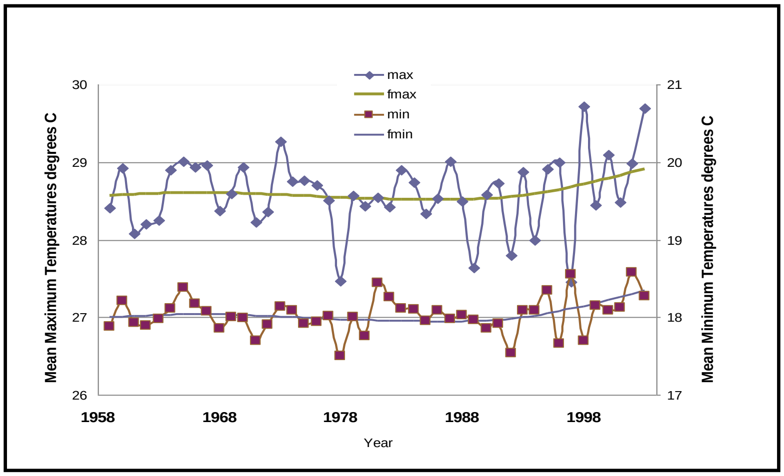

Figure 5. Mean maximum and minimum temperatures for the short rain season (Oct-Dec) at Makindu, Kenya (1959-2004)

2.2 Projected climate change scenarios:

According to the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report (AR4), the global average temperatures will increase by about 1.1-2.9^{0}C under low emission scenario and by 2.4-6.4^{0}C under high emission scenario by the end of this century. For Eastern Africa, the predicted changes under a medium emission scenario (A1B) are summarized in Table 1. The median predictions show an increase in both temperature and rainfall. Annual temperature of the region is projected to increase by about 3.2^{0}C and rainfall by about 11% towards the end of this century. For shorter time scales, IGAD Climate Prediction and Application Center (ICPAC) predicts that the mean annual temperatures in the region will increase by about 0.8-1.1^{0}C by year 2030 and by 1.5-2.1^{0}C by 2050 for the mid-range emission scenario, A1B (ICPAC, 2007). At the same time, the assessment predicts that the rainfall in the region will increase by 0.6-9.7% and 1.1-18.8% by 2030 and 2050 respectively, for the same emission scenario.

Table 1: Temperature and rainfall projections for Eastern Africa (12^{0}S and 22^{0}E to 18^{0}N and 52^{0}E) from a set of 21 global models in the CMIP3 for the A1B scenario by 2100 (IPCC, 2007)

Season	Temperature response (oC)					Precipitation Response (%)					Extreme Seasons (%)		
	Min	25	50	75	Max	Min	25	50	75	Max	Warm	Wet	Dry
DJF	2.0	2.6	3.1	3.4	4.2	-3	6	13	16	33	100	25	1
MAM	1.7	2.7	3.3	3.7	4.5	-9	2	6	9	20	100	15	4
JJA	1.6	2.7	3.4	3.6	4.7	-18	-2	4	7	16	100		
SON	1.9	2.6	3.1	3.6	4.3	-10	3	7	13	38	100	21	3
Annual	1.8	2.5	3.2	3.4	4.3	-3	2	7	11	25	100	30	1

Notes: The table shows the minimum, maximum, median (50 %), and 25 and 75 % quartile values among the 21 models for temperature (°C) and precipitation (%) change. Numbers in the Extreme Seasons columns indicate a change in frequency of extreme seasons the increase is positive.

Despite the availability of overwhelming evidence in support of climate change at global and regional levels, uncertainty prevails over the exact nature and consequences of climate change at local level, making it difficult to plan and develop appropriate adaptation strategies, programs, and technologies. Global level simulations using climate models provide various scenarios with high levels of confidence but these predictions become less clear as to the magnitude and timing of the changes at sub-regional, national and local levels, and according to IPCC difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales. For example, the downscaled median values for rainfall show a 71% increase for Katumani and 50% decrease for Gedarif (Table 2). These are highly significant changes but with very high levels of uncertainty. These predictions are expected to improve in the coming years with better downscaling techniques.

Table 2. Downscaled rainfall projections for some locations in Eastern Africa from a set of 11 global models in the CMIP3 for the A1B scenario

Location	2046-2065			2081-2100		
	Min	Med	Max	Min	Med	Max
Katumani (Kenya)	23.9	41	57.6	30.9	70.9	96.9
Melkassa (Ethiopia)	-27.6	1.9	39.6	-16.6	1.5	35.0
Same (Tanzania)	-1.1	8.6	29.2	-0.8	18.9	51.9
Gedarif (Sudan)	-74.9	-48.5	-42.2	-77.7	-49.6	-31.9

Though there are problems in predicting accurately where, when, and by how much climate changes, based on our current knowledge and understanding there seems to be a general agreement among the scientific community about the changes as listed below. Since these projections are based on several assumptions of greenhouse gas emissions and nature of future socio-economic development, the magnitude and direction of these changes can change with changes in underlying assumptions.

1. The region will be warmer by about 1^0C by 2030 and by about 2^0C by 2050
2. The region is expected to receive slightly higher rainfall, especially during the period September to February
3. The region will also experience an increase in the frequency of both extreme wet and dry seasons
4. The region will experience an increase in the variability of rainfall both between and across the seasons
5. The changes in temperature and rainfall will lead to significant changes in the extent and distribution of arid and semi-arid climates especially in Tanzania, DR Congo and Madagascar

3. Impact of climate change on agriculture:

Rainfall and temperature regimes are perhaps the most important factors in determining the potential productivity of various agricultural enterprises either directly or indirectly. The direct effects of rainfall and temperature determine the suitability, rate of growth and potential yield of crops while the indirect effects influence the supply of nutrients and water through changes in nutrient and hydrological cycles. Annual crops with short production cycles are considered to be much more sensitive to changes in seasonal climatic conditions compared to perennials with growth cycles covering several seasons or years. The extent to which climate change affects crop production at a given location, among others, depends on current climatic conditions at that location, type of crops grown, level of management, and status of soil and other resources.

There are many pathways through which climate related factors can affect crop yields (both positively and negatively) and crop suitability. Firstly, changes in temperature and precipitation lead to changes in evaporation from the soil and transpiration from vegetation. Hence, higher temperatures will lead to increased demand for water by plants which are difficult to meet, especially when rainfall is expected to decline and become more variable. Secondly, different crops have different optimal growing conditions and high temperatures can make the crops unsuitable for growing in some areas where the current climatic conditions are already close to the maximum tolerable limits. Major shifts in production zones are predicted in case of crops with a narrow optimal temperature range such as coffee and tea. Thirdly, crops grow faster and mature earlier under warmer temperatures compared to cooler temperatures. The available data indicate that duration of several crops will be reduced by about one-two weeks with every degree increase in temperature, depending on current temperatures at that location and type of crop grown. This reduction in the time that a crop takes to mature will also reduce the productive potential of these crops. Studies using crop simulation models broadly indicate that potential for biomass production will decline by about 500 kg/ha with every one week reduction in the duration of the crop. Fourthly, some crops may benefit from increased concentration of CO_2 in the atmosphere. The response of crops to increased CO_2 concentration, often referred to as “CO_2 fertilization effect”, varies among plant species. Plants with “C-3” photosynthetic pathway, which include potato, beans, rice, wheat and many weed species, can benefit from this phenomenon but no significant benefit is expected in case of crops like maize, sorghum and millet with “C-4” photosynthetic pathway. Further, attaining these benefits requires high levels of management including use of fertilizer, optimum conditions for root growth, and control of weeds, pests and diseases. Under the prevailing low input management scenario, it is very unlikely that the region will be able to benefit from this phenomenon since other factors will continue to provide the overriding constraints to crop growth and yield. In addition to these direct effects, climate change will also affect crop production by reducing the capacity of natural resources to support productive agriculture. These include decline in soil fertility from increased mineralization, reduction in plant available water due to increase in evaporative demand of the atmosphere, increase in erosion and soil degradation and changes in the distribution and incidence of pests and diseases including weeds. All these changes will have significant impact on productivity, food security, and profitability both at household and national level.

Given the large number of factors and their many interactions, high spatial and temporal variability in the climate, soil and other resources supporting crop production and high level of uncertainty associated with future climate projections, it is extremely difficult to estimate precisely how the productivity of crops is going to be affected by changes in climate. Recent studies have used a variety of approaches to assess the likely impacts of climate change on SSA agriculture, ranging from quantitative crop simulation modeling (Jones and Thornton, 2003; Abraha and Savage, 2006; Walker and Schultze, 2008) to statistical time series analyses (Lobell et al., 2008). A more recent study, focusing on maize, sorghum, millet, groundnut and cassava, (Schlenker and Lobell 2010) combined historical crop production and weather data into a panel analyses and were able to produce a robust model of yield responses to climate changes. Their projections showed that the mean aggregate production changes for maize, sorghum, millet, groundnut and cassava were –22%, –17%, –17%, –18% and –8% respectively. A number of other studies that assessed impacts of climate change on agriculture in SSA have in general concluded that the effects are largely negative and advocated serious efforts to adapt to the progressive changes in climate.

4. Adapting agriculture to climate variability and change

Adapting agriculture to climate change is an ambiguous task due to various reasons that include long-term nature of change, uncertainty in predicting the magnitude of change, likely impacts (both negative and positive) and unquantifiable inherent ability of natural systems and practitioners to adapt to the gradual changes in climate. Further, the impacts may not necessarily be linear, there may be thresholds beyond which impacts and resulting damages become catastrophic (Hansen, 2008). Although farmers continue to innovate and adapt, many studies indicate that they will be limited in their capacity to react and respond to the changes that are occurring much more rapidly than they have experienced before (Rao et al., 2011). More appropriate interventions that are based on deep understanding of historical and current trends in climate, sound science and meaningful analysis of costs and benefits are required to overcome adverse impacts of climate induced uncertainties of today and near future.

A number of different approaches were suggested as a way to adapt agriculture to climate variability and change. Among them are, integrated planning of land and water resources at plot and watershed scales to ensure that the synergies are properly captured, promoting activities that are geared towards improving soil fertility, diversifying agriculture with crops and varieties that can perform better under various climatic stresses, developing sound risk management strategies including safety nets and risk insurance, and adaptive management that disseminates timely climate information to farmers and tailors techniques to shifting climatic conditions. An integrated approach that combines all these elements is often referred to as “Climate Smart Agriculture” which addresses both adaptation and mitigation objectives. It is defined as agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals (FAO, 2010). The technological components that are suggested under these strategies are mainly aimed at sustainable intensification which is the key to ensure food security especially in countries where good scope for increasing current levels of productivity exists. Most of these technologies are not new but met with limited adoption by smallholder farmers (Table 3). Among the primary constraints that are affecting adoption these practices include season specificity of these technologies limiting economic benefits to certain type of seasons, high requirement of labour and capital investments per unit area, high input costs and uncertain returns and lack of access to information and inputs. Fundamental to these practical constraints is the variability in inter and intra seasonal rainfall and the inevitable uncertainty that it imposes on farm production and returns on investments.

Table 3: Potential options for farmer adaptation to climate variability and change and benefits and constraints to adoption

Suggested adaptation practice	Potential benefit	Constraint to adoption
Change in crops/varieties	Other crops and varieties more suitable to new climates	Timing of shift and availability of appropriate crops. Market for some crops may not be attractive. Choices may be limited for very dry environments
Drought and heat tolerant varieties	Covers risks from extremes	Low yield potential and may not be beneficial in normal and good seasons
Soil and water conservation	Increase soil water availability, moderate effects of droughts	Amount of water conserved is limited by profile water holding capacity and benefits are associated with use of other productivity enhancing technologies
Fertilizer use	Increase yields and arrest nutrient depletion	High cost and risk on investment. Some places access is a problem
Seasonal climate forecasts	Tactical decisions to match management to seasons potential	Reliability and availability in user friendly formats
Conservation agriculture	Increases yield, conserves soil and water and improves soil quality	Availability of residue and planting equipment
Diversify income sources	Non-farm income sources less climate sensitive	Limited opportunities in rural areas
Adjust planting dates	Crop growth matching to seasonal rainfall	Not appropriate to areas practicing dry planting and limited opportunities due to short growing period
Expand farm	Expand area under crops to increase production	Availability of land and labour and potential impacts on environment
Improved markets	Increase income by realising better prices and reduce vulnerability to price fluctuations	Not suited to areas with poor access to markets and possible conflicts with middlemen
Early warning systems	Avoid potential losses	Reliability and institutional support
Safety networks and insurance	Cover risks and encourages investments in improved technologies	High premium and low interest of insurers in dry areas where risk is high
Agro-forestry	Increases over all productivity and makes better use of rainfall	Availability of suitable trees and trade-offs

Development of interventions that reduce risk and enhance adoption of improved technologies is the subject of research under two projects supported by ASARECA-CGS - "Making the best of climate: Adapting Agriculture to Climate Variability" and "Managing Uncertainty: Innovation Systems for Coping with Climate Variability and Change". Studies carried out under these projects have made significant contributions to improve the understanding of uncertainty and risk associated with variable rainfall and in developing management options that not only minimize risks during below normal seasons but help farmers take advantage of opportunities created during normal and below normal seasons. Here we briefly summarise the findings from these studies and discuss their implications.

4.1 Understanding and evaluating climate risk

The process of risk management starts with an assessment of how the risk is perceived by farmers and how it is currently being managed. Over the years, farmers have developed and adapted successfully to the fluctuations in climate across and during the years through keen observation, experimentation and practice. The role and value of this local indigenous knowledge in designing appropriate research, development and extension strategies that are relevant to the local conditions has long been recognized and is well documented (Chambers 1983; Richards 1985; Agrawal 1995; Carswell and Jones 2004; Chambers et al. 1989; Pretty et al. 1999). However, considering the complexity involved in understanding the trends in highly variable phenomena such as rainfall, doubts have been expressed on the ability of farmers to accurately discern climate trends from their casual observations (Kempton et al., 1997), the completeness of their assessment since they represent simplified versions of complex reality (Johnson-Laird, 1983) and the subjective nature of these perceptions (Beal, 1996; Marra et al., 2003; Pannell et al., 2006; Sattler and Nagel, 2010). Further, farmers' perceptions are also likely to be shaped by the agro-economic performance of crops and other farm enterprises that affect their livelihood where climate is only one of the many bio-physical and socio-economic factors that affect productivity. Farmers' perceptions are also expected to be influenced by a range of other factors such as gender, level of education and farm size.

Studies conducted in five districts of Eastern Kenya viz., Machaos, Makueni, Kitui, Mwingi and Mutomo to assess farmers' knowledge and understanding of both short-term and long-term variability in climate and associated risks revealed that farmers, in general, have a good understanding and knowledge of the general climate at their location, its variability and the probabilistic nature of variability (Rao et al., 2011). However, their ability to estimate the frequency distribution of different events and discern long-term trends is more subjective. Farmers tend to attach higher significance to negative events or impacts leading to a biased estimation in the frequency of occurrence of negative events (Table 4). This has important implications in the assessment of risk and in subsequent decision-making. Their perception of higher risk results in them preferring techniques requiring low levels of cash investment and acts as a major deterrent in optimizing input use and taking advantage of improved technologies. This is one of the primary reasons for low levels of adoption of improved technologies such as use of fertilizers and improved seed.

Table 4: Distribution of different season types (%) as perceived by farmers and from analysis of historical climate data

Location	Farmer perception			Climatology		
	Good	Average	Poor	Good	Average	Poor
Kitui	34	37	29	65	17	18
Mwingi	26	32	42	41	30	28
Mutomo	21	33	46	42	26	31
Katumani	23	34	43	28	36	35
Makindu	8	29	63	18	23	59

The analysis of long term maize yields of Machakos and Makueni districts highlight the effect of these conservative approaches adopted by farmers on productivity of agriculture (Figure 6). While the practices adopted by farmers are performing fairly well in below normal and to some extent in normal seasons, they are unable to capitalise on the opportunities available during the normal and above normal seasons. The current district average yields of about 0.5 t/ha is very low when compared to the yields achieved in on-farm trials and on the farms of progressive farmers in the area.

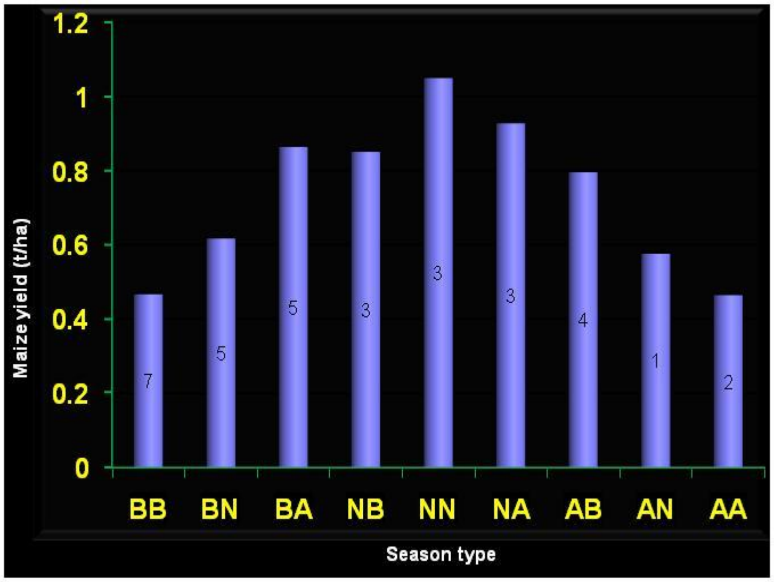

Figure 6: Maize yields of Machakos and Makueni districts during years with different types of seasons. (B=Below normal seasons with <250 mm rainfall, N=Normal seasons with 250-350 mm rainfall and A=Above normal seasons with >350mm rainfall. The two letters represent long and short rain seasons and numbers on bar refer to number of years)

Use of fertilizers is essential to improve productivity of inherently infertile soils. However farmers, in general, do not use fertilizers even though the productivity gains from use of fertilizers is well demonstrated and well known. One of the reasons for this is the risk and possible loss of investment made in this costly input. For example, results from simulation analysis conducted with long-term climate data from Katumani on maize yield with farmer practices of no fertilizer and improved practice with 40 Kg N/ha indicate that on an average use of recommended dose of 40 kg N/ha gives much higher yield than that achieved by farmers under low input system (Figure 7). However, in below normal rainfall seasons, maize yields are higher under low input system than in the improved system. Further analysis on returns to investment revealed that at Katumani farmers will realise the investment made in fertiliser in 65% of the years and will earn a good profit in 56% of the years.

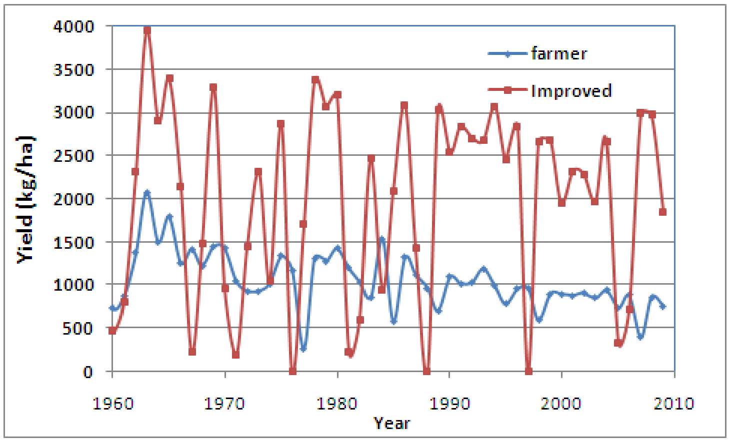

Figure 7. Simulated long-term maize yields at Katumani, Kenya with farmer practice of no fertiliser and improved practice with recommended dose of 40 kg N/ha.

An important implication of this assessment is that recommendations based on performance under mean conditions may not be appropriate in environments where climate variability results in high season-to-season variability in production. The recommended technologies should include adequate information on the risk and return profile of the proposed technology so that the end user can make informed decisions depending on their ability to take risk.

4.2 Managing climate risk

The uncertainty associated with climate variability, combined with inaccurate perceptions about risks and risk aversion on the part of decision makers, causes substantial loss of opportunity in climatically-favourable and even average years (Hansen et al., 2010). Farmers employ a range of strategies to protect against the possible losses which include selection of less risky but less profitable crops (Dercon, 1996) or cultivars (Morduch, 1990), under-use of fertilizers (Bliss and Stern, 1982; Binswanger and Sillers, 1983), shifting household labour away from farming enterprises (Rose, 2001; Rosenzweig and Stark, 1989), and shifting from productive to non-productive but more liquid assets as precautionary savings (Paxon, 1992; Fafchamps, 2003; Zimmerman and Carter, 2003). Most of these practices are very effective in reducing the risk but at the cost of reduced productivity. The resulting opportunity cost is a serious impediment to agricultural development efforts and hence rural livelihoods and agrarian economies. Hence, there is a need for increased attention to risk management options in order to deal effectively with year-to-year fluctuations in seasonal rainfall.

Risk management is the process of choosing appropriate methods to avoid, reduce, mitigate and recover from risks that smallholder farmers face from events that have different probabilities of occurrence. Effective risk management strategies should cover adequately all of these aspects and should assist in better preparing, managing and recovering from impacts of different magnitude and frequency. Such strategies can be broadly grouped into three categories.

1. ***Ex-ante adaptation options for better preparedness***: Actions taken before the event is realized to prevent or minimize losses from identified risks
2. ***In-season adaptation options for better management of emerging risks***: Actions taken in response to the nature of the rainfall season as it unfolds.

3. ***Ex-post adaptation options to facilitate better recovery from shocks:*** Actions taken after the risk is realized to minimize livelihood impacts of adverse climatic shocks. These are mainly associated with the relief and recovery programs and stress the need for shift from ad-hoc relief measures to planned interventions that aims at creating longer-term livelihood options is required for better vulnerability reduction

There are several opportunities that exist under each of the above three categories and a wealth of information was generated in the past few years on effectiveness of these options. These options open up new opportunities for smallholder farmers to increase productivity by making best use of available resources. The discussion here is limited to ex-ante and in season adaptation options.

4.2.1 Ex-ante adaptation options for better preparedness

Ex-ante management options can reduce exposure to risk, increase returns on assets and thereby contribute to increased productivity and profitability of farm enterprises. Farmers normally use strategies such as diversification with crops and varieties with varying tolerance to water deficits, intecropping/mixed cropping, planting larger areas, use low plant population, and use of moisture conservation including irrigation to ensure at least some harvest every year. Here, we discuss two potential options that received less attention from researchers in the region - use of seasonal climate forecasts in farm level decision making and crop insurance schemes.

Seasonal Climate forecasts:

One important and promising way of preparing for the forthcoming season is through use of seasonal climate forecasts. Seasonal climate forecasts though not perfect have sufficient skill to make more rational and informed decisions in preparing for the coming season. Globally, there is a growing interest in exploring the opportunities for forecast based farming, more so after the accurate prediction of 1997/98 El Nino event. The reliability and accuracy of these forecasts is improving rapidly with the increased understanding of the global climate system and factors influencing it. In case of Eastern Africa, good predictability was reported for October–December ‘short rains’ for the areas covering much of Kenya, eastern Uganda and northern Tanzania (Figure 8) while the skill of predicting ‘long rains’ is low (Mason, 2008). Hansen et al. (2011) after a thorough review of the available evidence from a combination of understanding of how climatic uncertainty impacts agriculture, model based ex-ante analyses, subjective expressions of demand or value, and the few well-documented evaluations of actual use and resulting benefit concluded that seasonal forecasts may have considerable potential to improve agricultural management and rural livelihoods. They have also identified constraints related to legitimacy, salience, access, understanding, capacity to respond and data scarcity as the main limitations for widespread use and benefit from seasonal prediction among smallholder farmers. Almost all the national meteorological services in the region issue forecasts on a regular basis though their use in agriculture remains under developed.

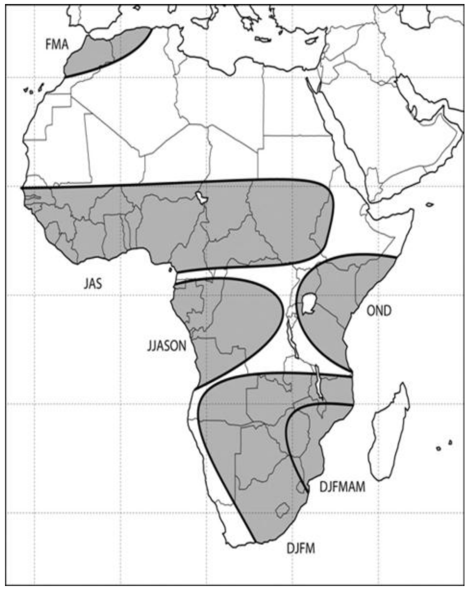

Figure 8: Predictability of rainfall across Africa (Source: Mason, 2008)

Since important farm decisions, whose outcome is highly sensitive to the amount and distribution of rainfall during the season, are to be made well before knowing the seasonal conditions, advance information about the rainfall during the forthcoming season has the potential to help farmers make more tactical decisions in planning investments and in adopting management practices that make best use of the season. The studies conducted in Kenya to evaluate the potential benefits from use of seasonal climate forecast information in planning farm operations have provided valuable insights about the usefulness of this information. The studies focused on three key issues, assessing the reliability of forecast information, the potential to change decisions and access to information in a format that could easily be understood, which are critical for farmers to make decisions based on seasonal climate forecast information.

Reliability of forecasts: There is considerable variation in the skill with which climate can be predicted for different locations but the predictability over much of the ECA region is high, mainly due to the high influence of the El Nino and La Nina phenomena on the local climate (Figure 8). Analyses of 'hindcasts' produced by International Research Institute for Climate and Society (IRI) for 43 seasons showed that the forecasts are generally reliable (Table 5). Out of the 19 and 24 seasons that are predicted to get below and above normal rainfall respectively, the prediction went wrong four times in each category. However, farmers considered that the failure of below normal season prediction is not a problem since it represents a lost opportunity and does not involve any losses on investment. But the wrong prediction of above normal season is a problem as it can lead to potential loss on investment. They have also indicated that for them to use forecast information in planning farm operations, it should be true in four out of five times and considered the current skill in the forecasting meets their requirement.

Table 5: Reliability of seasonal climate forecasts at Katumani, Machakos district, Kenya

Rainfall class	Total predictions	Hits	Misses
Below normal (<250 mm)	19	15	4
Above normal (>250 mm)	24	20	4

(Studies by Stewart et al. 1983 and crop simulation analysis with long term data indicated that a seasonal rainfall of about 250 mm is required to grow a good maize crop in this environment)

Potential to change decisions: The forecast to be useful should lead to a change in management decision and farmers in the pilot sites have identified a number of management decisions that can be based on forecast information. These include:

1. Selection of crops and varieties: They prefer sorghum and other drought tolerant crops and short duration varieties in the seasons predicted to be below normal
2. Allocation of land to different enterprises: Allocation of land for different crops and varieties such as more land for maize in seasons predicted to be above normal
3. Selection of management practices: Selection of a number of management practices such as use of soil and water conservation practices and use of fertilizer and other inputs can be made with forecast information
4. Asset development: Farmers have indicated that it is possible to use the forecast information in deciding number and type of livestock, keeping food reserves, etc.
5. Labour allocation: In the seasons predicted to be below normal they can look for more off-farm employment and if necessary consider temporary migration
6. Marketing the produce: It is possible to strategize the amount and time of selling produce and also buying inputs

Access in a format that can be easily understood: A weather based agro-advisory system was developed to communicate the forecast information timely in a format that can be easily understood by farmers. The advisory is an interpretation of the seasonal climate forecast issued by the national meteorological department (KMD) in consultation with scientists from national agricultural research institute (KARI) and local extension officers from Ministry of Agriculture in the target districts. The advisory provides a succinct summary of agricultural implications of the forecast that the team by consensus has agreed as the most appropriate/feasible for type of season predicted (Figure 9). The advisory is location specific and is based on rainfall data from the closest meteorological station. The probabilities are converted into amounts of expected rainfall using a program FACTFIT, developed by FEWSnet. The advisory was made available to the interested farmers through the office of local agricultural extension officer.

Figure 9. An example of location and season specific advisory

Farmer assessment of advisories: Though farmers preferred more specific information about the season including distribution of rainfall during the season and length of dry spells, they felt advisories include relevant information that they can use to tailor crop management to expected conditions. In practice, a broad indication (season likely to be good, average, poor) was found to be sufficient for making informed decisions. A survey conducted to evaluate the usefulness of the advisories showed that most farmers considered the advisories as extremely useful in planning farm operations, an observation well supported by a willingness of 87% of the farmers interviewed to pay for the service if required (Table 6).

Table 6: Farmer assessment of usefulness of advisories in planning farm operations and their willingness to pay for the service

Location	Total farmers (No)	Usefulness (%)			Willingness to pay
		Extremely useful	Somewhat useful	Not very useful	
Kitui	27	59%	33%	0%	81%
Mwingi	39	77%	29%	3%	85%
Mutomo	26	69%	22%	3%	96%

Crop insurance:

Insurance against crop loss is receiving increased attention as a means to cover losses from extreme events such as flooding and droughts and enhance the resilience to shocks. Crop insurance schemes are well established in developed countries where farming is practiced by large commercial farmers, but are new to developing countries where farming is mainly of subsistence nature that generates very little marketable surplus. In addition there are also problems associated with accurate assessment of risks in financial terms and high transaction costs due to involvement of large number of farmers over small areas. Index insurance is one approach that appears to be of considerable promise in the countries where agriculture is predominantly smallholder in scale. Index insurance allows large number of small holdings to be aggregated in a uniform area and involve low transaction costs since no verification is required. Index insurance is based on an objectively-measured index of how climate extremes affect crop production to determine certain climate triggers which when surpassed would support a compensation payment. The World Bank has supported the design and piloting of climate insurance schemes in India, Malawi, Mexico and many other countries across the world. In Malawi, the IRI designed insurance system allowed farmers to access loans that, in turn, provide access to inputs and the cash necessary to pay for the insurance premium (Hansen et al., 2010). Through this program, farmers were able to purchase hybrid seed and quality fertilizers needed to be more productive. The number of farmers who purchased insurance increased from 892 in 2005 to several thousand contracts in the 2006-2007 seasons. ILRI in collaboration with UAP Insurance Ltd. and Equity Bank is piloting an index-based livestock insurance program in the arid Marsabit district of Kenya. In this case, the index is based on the availability of forage estimated using satellite imagery. Payments are triggered when the satellite images show that forage has become so scarce and animal mortality is expected to be in excess of 15 percent within the defined geographic area. In Ethiopia, a different type of insurance project was designed and tested to address national food security (Stayton and Hess, 2006). The insurance, developed in cooperation with the WFP, is purchased by the Ethiopian government to provide funding for food aid in response to large droughts. When rainfall across several locations in Ethiopia is low enough that it is likely to lead to substantially lower maize yields, the WFP receives an insurance payout to supplement its relief budget for those years.

One of the limitations in developing and implementing such schemes in the region is related to the availability of climatic data. Good historical weather records to analyse and design the index and extensive and reliable network of weather stations for monitoring current climate are the two important prerequisites in designing index based insurance schemes. Another problem with index based schemes is that payments are connected to the climate surpassing a certain trigger and losses if any before the reaching the threshold attract no payment. Such schemes generally involve collaboration between various organizations usually involving private and public sector institutions. Substantial investments are required to develop the product and explain it to the farmers and it is unlikely that insurance companies develop these products unless facilitated by the national governments or organizations such as the World Bank or Africa Development Bank. The low capacity of farmers to pay the premium is another important hurdle in promoting these schemes. Some countries such as India, Brazil and Mexico are promoting these schemes by subsidizing the insurance premium.

4.2.2. In-season adaptation options for better management of emerging risks

There are several well researched options which when adopted have the potential to reduce risk and even take advantage of the conditions depending on how the season progresses. These are simple, inexpensive and efficient technologies requiring low levels of investment but the potential benefits from these technologies are very high. Some of them are based on indigenous knowledge. Few examples of such interventions are presented here.

a. **Seed priming:** Seed priming is a simple strategy to make seeds germinate faster and achieve a good plant establishment. Seeds normally spend a great deal of time just absorbing water from the soil. Priming hastens germination and seedling emergence by reducing the time required for imbibing water from soil. Farmers from Nepal and Botswana have used this technique for generations especially when the onset of rainfall is delayed to catch up on time lost to drought. This simple technology has several advantages. Primed seed usually emerges from the soil faster, and more uniformly than non-primed seed of the same seed lot. This helps in establishing the plant quickly and in overcoming moisture stress from early period dry spells. Faster germination and emergence result in rapid development of seedling root system while conditions in the surface layers are still favourable and hence are able to survive better by making better use of moisture stored in the lower layers. It is also observed that in some instances primed crops compete vigorously with weeds and escape pest attacks. The crops flower early, mature earlier and give higher yields. It also provides a means to supply some nutrients that are required in small quantities by crops. For example in acid soils of Eastern Africa legumes do not grow well because they cannot take up enough molybdenum. In some soils phosphorus is a constraint. Substantial yield benefits can result from the addition of tiny amounts of molybdenum to the priming water or by treating the primed seed with small quantities of soluble phosphorus. Researchers from CAZS natural resources, University of Wales, Bangor have conducted extensive research in several countries to establish safe limits – the maximum length of time for which seeds can be soaked and evaluate benefits (Table 7) for a wide range of tropical and sub-tropical crops (Harris, 2006).

Table 7. Summary of crops responding positively to on-farm seed priming

Crop	Soaking time (hrs)	Countries	Largest yield benefit observed (%)
Wheat	12	India, Nepal, Pakistan	37
Barley	12	Pakistan	40
Upland Rice	12-18	India, Nigeria, Sierra Leone, Gambia, Cameroon	70
Maize	12-18	India, Nepal, Pakistan, Zimbabwe	22
Sorghum	10	Pakistan, Zimbabwe	31
Pearl millet	10	Pakistan	56
Chickpea	8	Bangladesh, India, Nepal, Pakistan	50
Mungbean	8	Pakistan	206
Finger millet	8	India	15

b. **Transplanting:** Transplanting seedlings is another strategy to extend crop growing period in the areas where length of growing period is short or reduced by delayed on-set of rains. Transplanting is a technique more commonly practiced with rice and vegetable crops. In areas of Africa and Asia, transplanting of cereals such as sorghum and pearl millet is a traditional practice used to either fill gaps after crop emergence and thinning or to compensate for growth period that is insufficient to complete crop cycle (Rehm, 1989; BOSTID, 1996). Transplanting maize is not common except in some countries under irrigated systems. Transplanting is usually done by raising nurseries about a month earlier to onset of rains on small plots near the homes using small amounts of water. Transplanting, besides increasing yields, was found to contribute to stabilization of yields and avoiding loss of crop in some seasons. Studies conducted in Tigray and Afar regions of Ethiopia revealed that transplanted sorghum flowered 10-25 days early and matured 50-65 days earlier than the sorghum direct sown at transplanting time (Assefa et al. 2007). Further, the transplanted sorghum recorded about 1.0-1.8 t/ha higher yield compared to normal sowing with onset of rains. In the studies conducted by Oswald et al. (2001) in Western Kenya, yield losses from striga infestation was found to be significantly less than that in direct seeded crop. Striga densities were considerably low when maize seedlings of more than 17 days old were planted. The main constraint here is high labour requirement.

c. **Response farming:** Detailed studies were conducted in Kenya on response farming in a project aimed at designing sustainable and flexible cropping systems for low resource farmers in marginal rainfall zones, characterized by great seasonal rainfall variability, uncertainty, and recurrent drought. The method uses date of onset of the rainy season as predictor to assess the amount and distribution of rainfall during cropping season. Stewart and Faught (1984) found that seasons with early onset are superior to late onset seasons and last longer. The critical date separating early onset from late onset is selected form the graph of season rainfall duration versus date of onset and was used as the first decision tool to select varieties of appropriate duration. Continuous monitoring of the season and relating it to the observed long-term trends are used to make necessary decisions on fertilizer application, plant population adjustments and other agronomic decisions. Though found to be very effective, there are constraints in terms of communicating the information regularly and timely to farmers. While all components of response farming such as reducing the number of plants after certain amount of moisture deficits may not be practical, some components of this systema re extremely useful in planning farm operations under uncertainty.

d. **Microdosing of fertilizer:** Low use of fertilizers is one of the major factors contributing to the low levels of crop yields in the region. Given the risks involved with an unpredictable climate, farmers are not willing to invest in fertilizers to replenish the soil, and consequently soils are depleted, yields and crop quality decline, and hunger and under-nutrition are exacerbated. Use of small doses of expensive fertilizer is a precision-farming technique that helps farmers overcome this problem. ICRISAT has carried out research on effectiveness of microdosing at several locations in many African countries. The technique involves application of small, affordable quantities of fertilizer onto the seed at planting time, or a few weeks after emergence. The technique was found to make optimum use of fertilizer with high levels of use efficiency making it an economically viable option for the farmers. Considering the potential of this technique, private fertilizer companies in many countries are now making fertilizer available in small packets suited to the resource constraints of small-scale farmers.

e. **Contingency plans:** A contingency plans define how a household will recover from a critical event to resume normal operation. Unfortunately not much work was carried out in the region in developing location specific contingency plans that suggest effective management alternatives for situations like early, mid and late season dry spells of differing intensity and frequency.

5. Conclusions

Farming in dryland areas is a risky enterprise and primary source of that risk is variability in climate. Projected changes in climate are expected to make the situation worse, with increased variability in rainfall and more frequent occurrence of extreme events. Managing risks associated with variable climatic conditions is a difficult task but opportunities exist. Research carried out in the region under projects supported by ASARECA-CGS and CCAA program of IDRC/DFID has identified such opportunities which when promoted will lead to significant benefits. Key lessons from this research are as follows:

a. In general, inadequate attention was paid by researchers and development agencies in managing production risks associated with variability in climate. Recommendation and promotion of most technologies is based on the performance under average conditions with little or no attention to possible risks and costs involved. As a result adoption of these technologies by risk averse small holders remained low.
b. Farmers' perceptions of climate variation, risk and change are complex. The evidence suggests that they over-estimate risks of negative impacts and thereby adopt conservative low input agriculture that covers risks but cannot make use of good conditions when they occur. The resulting opportunity cost is the profit foregon.
c. Climate change is real with potential for significant negative consequences. For adaptation related work, more accurate projections about the potential changes at local level are required. At this stage there are still problems in downscaling and developing site specific scenarios. Hence, adapting to risks associated with current climatic conditions is an essential first step towards adapting to future changes in climate.
d. Research and development organizations should consider developing and promoting risk management strategies that are based on systematic use of historical and current weather/climate information. Seasonal climate forecasts, especially for locations with high predictability, are extremely useful in making farmers take tactical decisions in planning and managing their resources and thereby reduce risks and achieve higher levels of productivity.
e. Several low cost low risk technologies with a potential to improve productivity are available. These are mostly technologies developed from indigenous knowledge and are easy to adopt. Promotion of such technologies can lead to significant gains in both increasing productivity and adapting to current and future climate uncertainties
f. Developing and implementing contingency plans defining effective actions to minimize unanticipated damage from climate events at farm and local level is an important strategy that is not very well developed in the region. There is a need for research and development organizations to put in place such measures to create awareness and provide timely advise in managing climate related risks.
g. Strengthen the capacity to make better assessment of impacts of climate variability and change. Understanding how systems perform under different climate scenarios and how the negative impacts can be mitigated is an important prerequisite in formulating effective adaptation options. Crop simulation models and other tools are extremely useful in making such assessments and currently the region has very limited capacity in using such tools. There is an urgent need to strengthen the formal and informal education by including them in the curriculum of formal university level education and by developing appropriate short term training programs
h. Institutional arrangements that can better link relevant institutions to work together and complement each other's strengths are required both at national and regional levels. No good collaboration exists between meteorological and agricultural research institutions at national level and the links between research and extension are also weak.

6. Way forward

ASARECA as a regional organization has done well to place adaptation to climate variability and change high on the research agenda by identifying it as one of the priority areas for research in its current and previous strategy documents and by initiating and supporting research through its CGS system. These initiatives have led to significant achievements in creating awareness about climate issues, establishing teams of researchers in the participating countries, improved understanding about the role of climate variability in smallholder agriculture and in developing innovative approaches to reduce negative impacts of variable climate. However, not all countries benefitted from these initiatives and some of the products are yet to reach the scales where outcomes of these investments translate into on the ground actions and generate measurable impacts. ASARECA with a network of national, regional and international organizations as well as donors is well positioned to build on these initial successes. In looking to the future and suggesting possible ways in which ASARECA may continue to support climate risk management research, we suggest that ASARECA should work towards developing a more comprehensive well targeted regional research agenda centred around key problems that the region is facing. Considering that the research on climate issues is fairly new in the region, efforts should be made to develop effective partnerships between local and advanced research institutions to strengthen the local capacity. Following are some of the key issues which ASARECA can consider while building such initiatives.

i. Increased focus on climate issues: Despite the key role that climate plays in defining agriculture, it has not received the required attention by researchers and development agents. The current focus on climate issues, triggered by climate change and its potential impacts on smallholder agriculture, has opened up new opportunities to undertake more detailed evaluation of climate impacts on agriculture and develop and promote technologies that help smallholder farmers in effectively managing them. All ASARECA programs should consider supporting studies that quantify economic impact of climate variability and change as well as the benefits and develop management options aimed at minimizing the negative impacts. This can be achieved through integration of climate issues into on going activities or through reanalysis of data from previous studies.

ii. Promote better understanding of climate issues: Previous work highlighted the need to improve the understanding about impacts of climate variability and change on agricultural systems by all stakeholders from farmers to policy makers. Agricultural systems are complex involving integration of many processes and analysing them will be difficult. Problems with availability of good quality data and limited skills in analysing the available data are limiting the capacity of the organizations in the region to quantify and understand the effect of climate on productivity and performance of agricultural systems. There are also problems with separating effects of climate variability and change from the effect of other factors such as changes in soil fertility. Also impacts of climate change are not always negative and uniform across the region. There is a need to improve understanding of all stakeholders including planners, researchers, extension workers and farmers on issues related to climate variability and change and on the possible location specific impacts.

iii. Address the current challenges: Climate change brings new challenges but it also highlights the need to address more comprehensively the same old problems that agriculture in the region is struggling to cope with. Since the projected impacts of climate change on agriculture tend to be extensions of the substantial challenges that climate variability already imposes, developing management options that could actually buffer against some of the more detrimental impacts associated with current variability in climate provides a good starting point to deal with future changes. Most practices aimed at strengthening and promoting sustainable agriculture can make significant contributions towards adapting agriculture to climate change and variability and in improving resilience of small scale agriculture. The need here is more on addressing the constraints limiting the adoption of these practices by smallholder than doing more research to develop new technologies. Since climate induced risk is one of the major constraints in adoption of these technologies, adaptation research should focus on developing and promoting effective risk management strategies such as those identified in this paper.

iv. Enhance the capacity of researchers in the region: Understanding how systems perform under a changing climate and how the negative impacts can be mitigated is an important prerequisite to formulate effective adaptation options. There are a wide range of weather driven climate risk assessment tools that provide valuable insights in climate-induced production risk as well as allowing the evaluation of the potential of a range of crop, pasture, soil and water management innovations to mitigate such risks. Such tools also have the ability to evaluate the implications of a range of climate change scenarios at a range of scales ranging from the plot, farm, catchment scales to the national and regional scales. The region has very limited capacity to use such tools and there is an urgent need to strengthen the formal and informal education to include them in the curricula. ASARECA in collaboration with partner institutions should work towards establishing core teams of researchers with relevant skills to develop and disseminate climate information products.

v. Networking of partners: Of particular interest here is the partnership between meteorologists and agricultural researchers. Research on climate issues can be more effective when climate scientists work together with agricultural scientists. In almost all countries in the region the collaboration between these institutions is very limited. The National Meteorological Services are the collectors and custodians of long-term climate data and are increasingly gaining the skills to analyze and use such data to deliver climate risk related products. As such, it is imperative that they are key research and development partners in the consideration of agricultural adaptation to climate change. ASARECA and partner institutions should make deliberate efforts to involve them as partners in the projects and programs involving climate studies.

vi. Promote sharing of knowledge and best bet technologies: The region is a diverse mix of countries with varying capacities and strengths. Researchers and practitioners throughout Africa are conducting climate related research under a number of initiatives including those supported by ASARECA-CGA but the available knowledge is not shared effectively for the benefit of all. Most research results end up in gray literature such as project reports with limited access. ASARECA can play an important role in developing a knowledge management system that allows efficient sharing of knowledge and experiences among institutions so as to promote rapid and effective uptake of innovative practices, technologies, and research results and to avoid duplication of research efforts.

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