2

Climate change and agricultural development

Tim Chancellor, John Morton, Ramadjita Tabo and Ralph von Kaufmann

Introduction

This paper discusses the influence of climate change on smallholder agriculture, with a special focus on West and Central Africa (WCA). The likely impacts of climate change on smallholder farmers are assessed and farmers' strategies for adapting to these impacts are examined, drawing on examples from the WCA region. Key research and capacity strengthening priorities are identified, that will help to minimize adverse impacts and identify new opportunities. The paper is aimed at all stakeholders in agricultural research for development, because climate change will be one of the central challenges facing agriculture in Africa. References are made to publications that deal with specific topics in more detail and a glossary of terms is provided at the end of the paper.

Agriculture and climate

Although an increasing number of people in sub-Saharan Africa live in urban areas, the majority of people still depend on agriculture as their main livelihood source. Agricultural crop production is largely determined by patterns of temperature and rainfall and changes in these patterns influence water availability in specific locations (Nkomo *et al*., 2006). Available moisture and the range of temperature affect the period during which conditions are suitable for crop growth. These factors also have a significant effect on livestock production, especially through impacts on vegetation in rangelands, on water availability for animals, on disease incidence and on the production of fodder crops.

Much of the agricultural production in sub-Saharan Africa takes place in arid and semi-arid areas where rainfall distribution is highly variable. More than 180 million people live in these fragile environments and they are highly vulnerable to conditions that lead to lower productivity. In West Africa, the Sahelian region is a particularly vulnerable environment and has become increasingly dry during the last 100 years. As a result, there has been a significant reduction in the length of the growing period for crops and a continuation of this trend would have very damaging consequences (Thornton *et al*., 2006).

Is the climate changing?

There is a growing body of evidence that global climate is changing (see Box 1). It is also becoming increasingly clear that this change is strongly associated with the increased emissions of greenhouse gases. Scientists from the Intergovernmental Panel on Climate Change (IPCC) have shown that global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased substantially as a result of human activities since 1750. The use of fossil fuel and land use change are mainly responsible for the increase in carbon dioxide. Agriculture is the prime contributor to the increases in methane and nitrous oxide. The IPCC strongly believes that there is a link between human-induced activity and global climate change. It now states that *most of the observed increase in global average temperatures since the mid-20th century is* very likely *due to the observed increase in anthropogenic greenhouse gas concentrations*.

The IPCC projects that an average increase in global temperatures of about 0.2°C per decade will occur, taking into account a range of emission scenarios. For West Africa, warming by 2080-2099 will be higher than this, with an average across models of 3.3°C, and higher, above 4°C, in the far north of the Sahel countries. It also states that even if the concentrations of all greenhouse gases and aerosols were kept constant at year 2000 levels, temperature increases of about 0.1°C per decade are probable. This means that it will be essential to develop suitable adaptation strategies as well as to find ways to reduce future emissions.

West Africa is one of the regions of the world that presents most uncertainty as regards future trends in precipitation. An average of the major models suggests a modest increase in rainfall for the Sahel with little change on the Guinean coast, although there are models which project either strong drying

Box 1. What is the evidence for climate change?

Is global climate really changing in the way that many scientists are claiming? Critics point out that there are gaps in our scientific understanding of climate trends. They also maintain that there have been large changes in global climate in the past and that these cannot be attributed to human activity. Scientists who believe that climate change is occurring state that this is happening more rapidly than ever before. A recent report of the Intergovernmental Panel on Climate Change (IPCC) concluded that *warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level*.

- Eleven of the twelve years from 1995 to 2006 are amongst the warmest years since 1850.
- Based on historical records, a warming of approximately 0.7°C over most of Africa during the 20th century is reported in the IPCC TAR . Observational records show that this warming occurred at the rate of about 0.05°C per decade with slightly larger warming in the June-November seasons than in December-May. Very high temperatures records have also been indexed e.g. the 5 warmest years have all occurred since 1988.
- Between 1961 and 2003, global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year.

Furthermore, in recent decades variability in climate and the frequency of extreme events have increased significantly.

- Droughts have become more intense and of longer duration since the 1970s, especially in the tropics and subtropics.
- Heavy precipitation events have occurred more often over most land areas.
- There have been fewer cold days, cold nights and less frost.
- The frequency of hot days, hot nights and heat waves has increased.

Source: IPCC (2007)

or strong moistening. Models suggest an increase in the number of extremely wet years and seasons, with much weaker projections of drought, except in the far north of the region.

Other effects of climate change that will have direct or indirect consequences on agriculture are rises in sea levels which will lead to flooding in coastal areas. Coastal West Africa has been identified as a highly vulnerable area with both urban and rural communities at risk. Adverse impacts are likely to occur on coastal marine fisheries and populations will be exposed to an increased risk of infectious diseases as a result of flooding. Declining human health will have a negative effect on labor productivity in agriculture.

Vulnerability of smallholder farmers

The negative impacts of climate change will be felt most severely by people in poor countries, many of them in sub-Saharan Africa (Stern *et al.*, 2006). Most of these people live in rural areas and have access to only limited areas of land for cultivation or livestock production. Smallholders cultivate more than 70 percent of crop land in West Africa but produce a large proportion of food and cash crops. For example, in Nigeria smallholders produce over 90 percent of several food crops, including rice and wheat, and cash crops such as cocoa and cotton (Jazairy *et al.*, 1992). These farmers live in diverse and risk-prone environments, with very limited access to agricultural inputs like fertilizers and good quality seeds and are seriously affected by climate variability and increases in levels of crop and animal disease. Because of their limited livelihood options and scarce resources they are also highly susceptible to market and governance shocks.

It is widely believed that unless the livelihoods of these smallholder farmers and the resource base upon which they depend can be made more resilient through a better understanding and management of current climatic variability, the challenge of adapting to future climate change will be daunting for most and perhaps impossible for many.

Impacts of climate change on agriculture

Most of the research on the likely effects of climate change on crop productivity has been done on the major world cereals and cotton with little attention given to root crops, sorghum and millet, legumes, oilseeds, tropical fruits and other commodities that are important in the WCA region. The available evidence suggests that overall impacts on rainfed agriculture will be strongly negative, with crop yields reduced by up to 50 percent (IPCC, 2007). In tropical areas, adaptation measures may prevent yield losses in cereals where only limited warming occurs and there may be some benefits from the so-called *fertilization effect* of enhanced levels of CO_2 (see Box 4). Once mean temperature increases reach about 2^0C, significant yield losses will result even with adaptation (see Figure 1 for tropical maize).

Effects on crop tolerance are not only caused by changes in mean temperatures. Short term variations in temperature can have limiting effects on key developmental stages even in the absence of mean temperature rises (Porter and Semenov, 2005). For example, it has been shown that grain fertilization and grain set in wheat is very sensitive to the maximum temperature at mid-anthesis and that grain yield declines at accumulated temperatures above 31^0C (Ferris *et al.*, 2000). As current projections show an increased frequency of extreme events, including high temperatures, the implications for crop productivity are potentially serious. Similarly, the increased temperatures will increase heat stress on livestock, which may lead to higher levels of mortality, especially in taurine cattle.

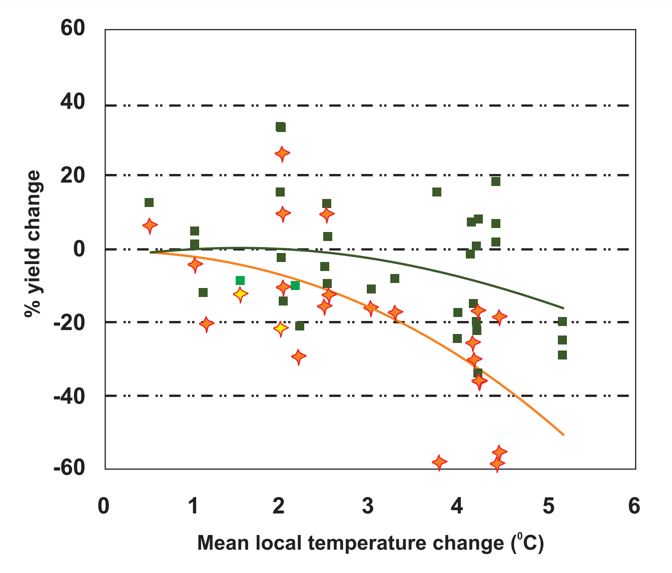

Figure 1. Sensitivity of tropical maize to mean local temperature change without adaptation (red dots) and with adaptation (dark green dots). Modified from Easterling et al., 2007.

Even given the uncertainty about rainfall regimes discussed above, increased water requirements for crop growth, from increased warming, are likely to be widespread within the WCA region. Where rainfall is reduced and/or more variable the production and the quality of forage for livestock in rangelands may be adversely affected.

Climate change will have consequences for pests and diseases of both crops and livestock. Increased abundance of some insect vectors is likely in areas where temperature rises and moisture is not limiting (Chancellor and Kubiriba, 2005). This may lead to an increased risk of cassava mosaic disease and maize leaf streak disease which are transmitted by whiteflies and leafhoppers, respectively. Hotter and drier conditions are likely to favour Sorghum head smut, an important soil-borne pathogen. By contrast, some other fungal diseases such as leaf blights of sorghum and maize may decline in importance under these conditions. For livestock, a major concern (though not currently in WCA) is the risk of increased incidence of rift valley fever.

Another important potential adverse impact of climate change is the loss of biodiversity as some plants and animal breeds are unable to adapt to the new conditions. This includes fish species in inland and marine fisheries where increased water temperatures will affect fish and their habitats.

Farmers' adaptation to climate change

Over long periods of time farmers in sub-Saharan Africa have demonstrated resilience to unfavourable environments by evolving short-term 'coping' strategies to manage specific hazards, and longer-term adaptations to address variability in environmental conditions; for example, by changing the way they manage labour inputs. Farmers modify crop planting dates to adjust to changes in the onset and cessation of rainfall. Similarly, they utilize early maturing varieties or more drought-tolerant crops where moisture becomes limiting and they practice intercropping or mixed farming to reduce the risk of total crop failure. Farmers harvest water or, where this is feasible, they adopt irrigation practices such as the drip irrigation system developed for vegetable production in parts of Senegal.

Adaptation or coping strategies can be broadly grouped into activities aimed at (a) diversification (risk spreading) of both farming and other associated livelihood enterprises *prior to the onset of the season* and (b) activities which *respond to specific seasons as they evolve*. Matlon and Kristjanson (1998) provide an example of such a matrix to describe such coping/adaptation strategies in the semi-arid tropics of West Africa and also consider the 'spatial scale' at which the various strategies operate (Box 2).

Farmers' ability to adapt to climate change will build on adaptation to climate variability, but will be influenced by a range of factors including the extent to which they are affected by other constraints. Where population is increasing rapidly and land degradation has reached a critical level, farmers will be less able to manage the impacts. Similarly, high incidences of HIV/AIDS and of vector-borne diseases will reduce their ability to cope. In some cases, where farmers have little previous experience of adapting to climate variability they may be more susceptible to the effects of climate change even though they may live in relatively favourable environments. This appears to be true of some livestock keepers in relatively wet areas as they have not had to cope with the effects of drought in the past. Consequently, farmers' adaptation strategies should be seen in the context of their overall situation. In many cases, adaptation strategies are likely to involve maximizing the generation of income from non-agricultural sources.

Box 2. Coping/adaptation strategies used by farmers in semi-arid West Africa.

Scale	Time Frame		
	Before the season	**During the season**	**After the season**
Plant	Varietal selection for stress tolerance / resistance	Replanting with earlier maturing varieties	
Plot	Staggered planting dates Low density planting Intercropping Run-off management Delayed fertilizer use	Changing crops when re-planting Increasing or decreasing plant density at re-planting or by thinning	Grazing of failed plots for animal maintenance
Farm	Diversified cropping Land type diversification Plot fragmentation	Shifting crops between land types	Late planting for forage
Household, village, region	Cereal stocks Livestock / assets Social and off-farm employment networks	Matching weeding labour inputs to expectations of the season	Asset sales for cereal purchases Food transfers Migration for employment

Source: Matlon and Kristjanson (1998)

Climate information

Farmers may be better able to make informed decisions about how to manage their farming enterprise if they have more reliable climate information. Projections about changes in climate are largely derived from global circulation models which are becoming increasingly complex and sophisticated. These models do not provide information at local scales but regional models are now also being developed, such as the PRECIS model of the United Kingdom Meteorological Office. Climate prediction is extremely challenging in the WCA region because of the wide variation in vegetation, the role of land-use changes, the possible affects of atmospheric dust, and the influence of the oceanic jet stream. In addition, there are considerable barriers to smallholder farmers receiving, understanding, trusting and having the capacity to act upon, climate information.

Nevertheless, there are examples of where improved climate information has helped farmers to improve their decision-making (see Box 3), and further examples where government or other agencies working on behalf of smallholders have used climate information. In southern Africa climate information is being used to underpin crop insurance schemes (Malawi and South Africa) and to assist with flood management (Mozambique).

Box 3. Farmers' use of climate information in decision-making in Mali

Rainfed agriculture is the basis of the livelihoods of most people in rural communities in Mali. Managing the risks associated with variability in rainfall is one of their main concerns. In 1982, an innovative project was started which involved several different organizations led by the national meteorological service. The aim was to deliver agrometeorological information to rural communities and authorities in order to help them improve their decision-making in farming activities and food security. Technical support was provided by the Centre Régional de Formation et d'Application en Agrométéorologie et Hydrologie Opérationelle (AGRHYMET) and the World Meteorological Office. The project established a multidisciplinary working group whose main function was to act as a 'boundary institution' that bridges the gap between the climate and agricultural communities. The working group sought to achieve this by providing climate information and advice in ways that could be easily understood and used by farmers. The project is still continuing and a recent review has shown that it has resulted in several positive outcomes. These included:

- Some evidence for increases in yields of crops such as maize, sorghum and pearl millet by farmers using climate information compared with traditionally managed plots.
- A willingness by farmers to take more risks by investing in new technologies that can increase crops yields and income.
- Additional financial resources provided by the Malian government to the meteorological service for new weather stations and equipment.

However, a recent review of the project also acknowledged that the project's crop focus was narrow and the needs of livestock owners were largely neglected. There were difficulties in providing reliable local-scale information to farmers and it was not always easy to reconcile the different perspectives of different stakeholders. In spite of these constraints, the project is considered to have been successful and to provide useful lessons for other similar initiatives.

Source: Hellmuth *et al*. (2006)

Crop modelling

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, driven by daily climatic data, can be used to predict the impact of existing climate variability and change 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 thus provides a quick and much less costly opportunity of 'accelerated learning' compared with the more traditional multi-location, multi-seasonal and multi-factorial field trails. One such model that is becoming increasingly used by ICRISAT and her partners 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 amongst which maize, sorghum, pearl millet, chickpea, pigeon pea, soybean, groundnut, sunflower, cotton and trees are of importance in ICRISAT's mandated regions. (Dimes, 2005).

Research and capacity development needs

Most of the current research on the likely impacts of climate change on agriculture is targeted at the main cereal crops and cotton, with relatively little attention being given to other crops or to livestock and fisheries. With regard to crops, more research is needed on millet and sorghum and on tropical root crops, particularly cassava, yams and sweetpotato. Greater efforts are needed to identify opportunities for capturing potential benefits of climate change; for example, through increased productivity of certain beverage crops. Understanding of the impact of climate change on pests and diseases remains limited and more research is needed to improve knowledge in this area. Until now, research has focused on production aspects and more resources are required to address post-harvest issues, including storage, transport and marketing.

Action research is needed on the effects of climate change on farmer behaviour; on the feedbacks between short-term coping, long-term adaptation and the economic and policy context; and on how information flow between stakeholders can be optimized. There is also a need to assess current and expected future impacts and vulnerabilities, and the future adaptation options and pathways that may arise from the interaction of multiple stressors on the coping capacities of African communities (Boko et al. 2007). Farmers will require more support than before, particularly where their indigenous knowledge cannot be applied to new situations; for example, where new crops and cropping patterns are introduced. There is considerable scope to develop intercrops which maximize the use of available moisture without incurring a significant yield penalty. Farmer participatory research will become increasingly important and tools such as participatory plant breeding offer real opportunities to develop varieties that are adapted to local conditions.

Agricultural graduates will need a wider set of skills in order to enable them to work with farmers to develop appropriate solutions to new problems. In addition to the latest technical information, graduates will need to be able to analyse complex multi-faceted problems and develop suitable recommendations. They will also need to be able to interact effectively with different stakeholders and this will require good communication and facilitation skills. In a rapidly changing environment it will be important to keep up to date with new developments in agriculture and related fields. These emerging needs mean that new ways of teaching and learning are required to equip graduates with suitable skills. Provision also needs to be made for continuous learning through participation in initiatives such as the Forum for Agricultural Research in Africa's Regional Agricultural Information and Learning System.

Box 4. Glossary of terms

Climate
Climate is the statistical description of the weather in terms of the mean and variability of key variables such as temperature, precipitation, and wind relevant quantities over three decades. In a wider sense the “climate” is the description of the state of the climate system.

Climate change
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.

Climate sensitivity
The long-term (equilibrium) change in global mean surface temperature following a doubling of atmospheric CO_2 (or equivalent CO_2) concentration.

CO_2 fertilization
The enhancement of plant growth as a result of elevated atmospheric CO_2 concentration.

Feedback
When one variable in a system triggers changes in a second variable that in turn ultimately affects the original variable; a positive feedback intensifies the effect, and a negative feedback reduces the effect.

Greenhouse gas
A gas that absorbs infrared radiation and traps the heat in the atmosphere. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth’s atmosphere.

There is a need for improvements in how data are collected and information gathered as well as in the analysis, interpretation and dissemination of such data and information to end-users. In-country capacity needs to strengthened for generating, managing, processing and analysing data sets, for improving the quality of analytical tools, and for disseminating the results of these efforts in sectors that can contribute to climate change impact analysis. One way to do this is through the establishment of ‘hubs’ or centres of excellence established by Africans and developed by African scientists. This will help to also enhance institutional ‘absorptive capacity’ in the various regions, providing opportunities for young scientists to improve research in the fields of climate-change impacts, vulnerability and adaptation. (Boko *et al*. 2007).

References

Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda, 2007: Africa. *Climate Change 2007 (forthcoming): Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge

Chancellor, T.C.B. and Kubiriba, J. (2005). The effects of climate change on infectious diseases of plants. In: Infectious Diseases: Preparing for the Future. Office of Science and Innovation, United Kingdom.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K. Kwon, W-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J. Rinke, A. Sarr, A. and Whetton, P. Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Dimes, J.P. (2005). *Application of APSIM to evaluate crop improvement technologies for enhanced water use efficiency in Zimbabwe's SAT.* In Pala M, Beukes DJ, Dimes JP and Myers RJK (eds). Management for improved water use efficiency in the dry areas of Africa and West Asia: Proceedings of a workshop organized by the Optimizing Soils Water Use (OSWU) Consortium. April 2002, Ankara, Turkey. Aleppo Syria; ICARDA and Patancheru, India: ICRISAT. pp288

Easterling, W., Aggarwal, P., Batima, P., Brander, K., Erda, L., Howden, M., Kirilenko, A., Morton, J., Soussana, J-F., Schmidhuber, J. and Tubiello, F. (forthcoming) Food, Fibre and Forest Products. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*

Ferris, R., Ellis, R.H., Wheeler, T.R., and Hadley, P. (1998). Effect of high temperature stress at anthesis on grain yield and biomass of field-grown crops of wheat. Annals of Botany 82 (5): 631–639.

Hellmuth, M.E. Moorhead, A., Thomson, M.C. and Williams, J. (2006). *Climate Risk Management in Africa: Learning from Practice*. International Research Institute for Climate and Society (IRI), Columbia University, New York, USA.

Hulme, M., Doherty, R., Ngara, T. and New, N. (2005). Global warming and African climate change: a reassessment. In : *Climate Change and Africa* [Pak Sum Low (ed)]. Cambridge University Press, Cambridge.

IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jazairy, I. Alamgir, M. and Pannuccio, T. (1992). The State of World Rural Poverty: an Inquiry into its Causes and Consequences (NY University Press for IFAD)

Matlon, P. and Kristjanson, P. (1998) *Farmer's Strategies to Manage Crop Risk in the West African Semi-arid Tropics.* In "Challenges in Dryland Agriculture: a Global Perspective." Proceedings of the International Conference on Dryland Farming, August 15–19, 1988, Bushland Texas, USA pp 604 –606.

Nkomo, J.C., Nyong, A.O. and Kulindwa, K. (2006). The impacts of climate change in Africa. In: *The Stern Review on the Economics of Climate Change*.

Porter, J.R. and Semenov, M.A. (2005) Philosophical Transactions of the Royal Society B. 360: 2021–2035.

Pradeep Kurukulasuriya, Robert Mendelsohn, Rashid Hassan, James Benkin, Temesgen Deressa, Mbaye Diop, Helmy Mohamed Eid, K. Yerfi Fosu, Glwadys Gbtibouo, Suman Jain, Ali Mahamadou, Renneth Mano, Jane Kabubo-Mariara, Samia El-Marsafawy, Ernest Molua, Samiha Ouda, Mathieu Ouedraogo, Isidor Sene, David Maddison, S. Niggol Seo, and Ariel Dinar. 2006. The World Bank Economic Review, Vol. 20, No. 3, pp. 367–388

Thornton P.K., *et al.*, (2006). *Mapping Climate Vulnerability and Poverty in Africa*. Report to the Department for International Development.