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Climate change adaptation strategies in Sub-Saharan Africa: foundations for the future

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Cooper, P. J. M., Stern, R. D., Noguer, M. and Gathenya, J. M. (2013) Climate change adaptation strategies in Sub-Saharan Africa: foundations for the future. In: Singh, B. R. (ed.) Realities, Impacts Over Ice Cap, Sea Level and Risks. InTech Open, pp. 327-356. ISBN 9789535109341 doi: 10.5772/55133 Available at https://centaur.reading.ac.uk/32055/

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To link to this article DOI: http://dx.doi.org/10.5772/55133

Publisher: InTech Open

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Chapter 13

Climate Change Adaptation Strategies in Sub-Saharan Africa: Foundations for the Future

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/55133

1. Introduction

Many institutions across sub-Saharan Africa (SSA) and many funding agencies that support them are currently engaged in initiatives that are targeted towards adapting rainfed agriculture to climate change. This does, however, present some very real and complex research and policy challenges. Given to date the generally low impact of agricultural research across SSA on improving the welfare of rainfed farmers under *current* climatic conditions, a comprehensive strategy is required if the considerably more complex challenge of adapting agriculture to *future* climate change is to bear fruit. In articulating such a strategy, it is useful to consider the criteria by which current successful initiatives should be judged.

Ultimately, but possibly beyond the time scale within which funding agencies will specifically support climate change research in SSA, success will be measured by clear evidence that farmers are better able to cope with current climate-induced risk and adapt to future climate change as the need for the latter becomes imperative. However, for that to happen and for agricultural research to have made a significant contribution, in the shorter term there are key 'foundation stones' that must be in place upon which such research must be built. *It is the degree to which the support provided under current initiatives is able to help lay those foundation stones that success should be judged.*

In Section 2, a brief assessment of the complexities and challenges that face agricultural research is provided and then Section 3 describes the research approach for climate change adaptation for those challenges to be successfully addressed. Section 4 illustrates the key aspects of the foundation stones that need to be in place and by which successful support could be judged. The foundation stones have been grouped under three general headings: (i) Improved access to information (ii) Enhanced research capacity and (iii) Enhancing the

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impact of research. In the final section (Section 5), several recommendations have been suggested for actions that funding agencies and research institutions alike might wish to consider.

2. Rainfed agricultural development in Africa: A complex challenge

Rainfed agriculture in SSA has evolved gradually over the years in response to spatially very variable environmental conditions (principally rainfall, temperature and soil types) as well as diverse cultural, social and economic drivers. As a result, the types of farming systems that we see today are also very diverse, as are the development problems that they pose. The outcome has been that agricultural development, even in the absence of projected climate change, has already proved to be a challenging undertaking and after many decades of endeavour only moderate success has been observed.

In spite of the economic importance of rainfed agriculture in the region, both in terms of its contribution to National GDP and its role in providing a livelihood to a very high percentage of the human population, investment in this vital production system, and hence its productivity, has stagnated compared with other regions of the world where small-scale rainfed agriculture is important. As population continues to grow worldwide, increased food demand, hence a need for higher crop yields, has led to more intensive land use resulting in nutrient mining and degraded soils. Such nutrient depletion on a continent wide scale can only be reversed with the help of chemical fertilizers and hence fertilizer use trends can act as a useful proxy indicator of investment in agriculture. Average rates of fertilizer use have risen ten-fold, from 5 to 50 kg ha^{-1} in many parts of Asia and Latin America during the last 50 years whilst in SSA they have stagnated at a very low level of about 5 kg ha^{-1} from about 1980 onwards (Figure 1).

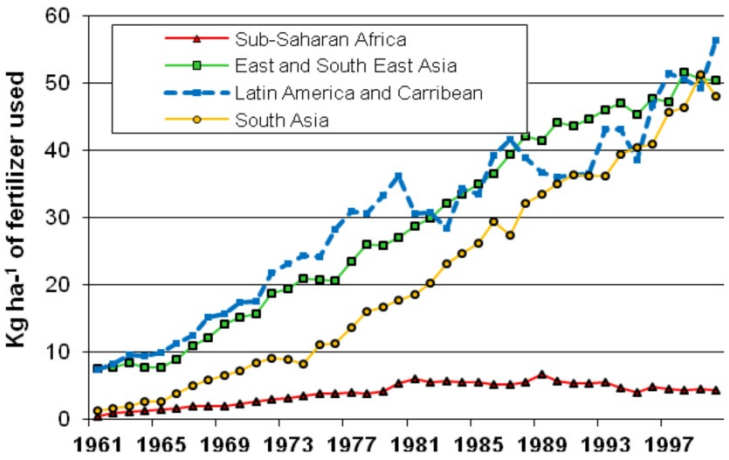

Figure 1. Fertilizer use trends (kg ha^{-1}) in Africa, Asia and Latin America: 1960-2003 [1]

There are many complex and interrelated issues that contribute to this state of affairs. The outcomes of lack of investment and low production of rainfed agriculture reinforce each other, leading to poverty traps and increased vulnerability of livelihoods to climatic and other shocks [2]. This has become well recognized and an emerging political will, both within and outside SSA, to support increased investment in rainfed agriculture is gaining momentum [3]. Nevertheless, for such investment strategies to produce the needed impact on a wide scale, favourable policies, institutional arrangements and basic development infrastructure are required for proper functioning of markets. An enabling investment policy environment would therefore include the existence of proper incentives, market access, information, input supply systems and the institutions required to reinforce their use [4, 5]. However, in many countries in SSA, low per capita incomes, debt servicing and negative balance of payments at the national level still undermine both the ability of governments to invest in basic infrastructure needed for markets and the private sector to operate effectively.

However, in spite of the emerging signs of greater commitment to rainfed agriculture in SSA, there is one fundamental characteristic of this sector that will continue to pose challenges. Rainfall variability, both within and between seasons, creates an underlying climate-induced risk and uncertainty for current farm-level production as well as for the potential impact of innovations designed to improve crop, soil and livestock management practices. This uncertainty discourages the adoption of improved farming practices and the beneficial 'investment' decisions required, not only from farming communities, but also from a wide range of additional agricultural stakeholders. They show an understandable reluctance to invest in potentially more sustainable, productive and economically rewarding practices when the returns to investment appear so unpredictable from season to season [6].

Overlaid on this challenging state of affairs is the accepted prediction that, whatever happens to future greenhouse gas emissions, we are now locked into global warming and inevitable changes to climatic patterns which are likely to exacerbate existing rainfall variability in SSA and further increase the frequency of climatic extremes [7]. '*Adaptation to climate change is therefore no longer a secondary and long-term response option only to be considered as a last resort. It is now prevalent and imperative, and for those communities already vulnerable to the impacts of present day climatic hazards, an urgent imperative*' [8]. This is the challenge that many institutions, and the funding agencies who support them, are attempting to address, namely to identify, investigate and promote climate change adaptation strategies for the diverse farming systems of SSA.

In undertaking research on strategies for adapting agriculture to progressive climate change, there is the need to understand the possible nature and timescale of those evolving climatic conditions to which farmers will need to adapt to. It is also important that the uncertainties associated with these projections are understood. Uncertainty in climate projections occurs from three principal sources:

i. Natural internal variability of the climate system – arising from factors such as variations in the therrmohaline circulation, El Niño-Southern Oscillation, and changes

in the ocean heat content. These are the natural internal processes within the climate system.

ii. Model uncertainty – climate scientists use climate models to project plausible future climate scenarios. These models are a physical representation of how the climate system works but there are still limitations in the knowledge of the process that govern the climate system coupled with limited computing resources.

iii. Scenario uncertainty – climate projections are based on emission scenarios, such as emissions of CO_2 and other 'greenhouse' gases. These scenarios are created based on assumptions on how the future will evolve, and of course there is considerable uncertainty associated with those assumptions.

The climate community is working to reduce these uncertainties [9, 10] through, for example, using multi-model ensembles. From these uncertainties, for seasonal precipitation, internal variability is the dominant source of uncertainty for the first few decades, while model uncertainty is the dominant source of uncertainty for longer lead times. *At the moment, adaptation decisions will need to be made in the context of high uncertainty concerning regional changes in precipitation.*

To try to account for these uncertainties the IPCC, in its latest report [7], assessed results from a range of Atmosphere-Ocean General Circulation Models (AOGCM) and provided climate projections for the end of the 21st Century. Projections from all these models show substantial agreement, but as might be expected, there are still considerable differences between the various models. For example, Table 1 provides information for East Africa generated from a set of 21 AOGCMs for one of the SRES emission scenarios group (the A1B scenario) focusing on the change in climate between the 1980 to 1999 period in the 20th century integrations and the 2080 to 2090 period of A1B. Table 1 shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for temperature (°C) and precipitation (%) change.

Month	Temperature Response (°C)					Precipitation Response (%)				
	Min	25	50	75	Max	Min	25	50	75	Max
DJF	2.0	2.6	3.1	3.4	4.2	-3	6	13	16	33
MAM	1.7	2.7	3.2	3.5	4.5	-9	2	6	9	20
JJA	1.6	2.7	3.4	3.6	4.7	-18	-2	4	7	16
SON	1.9	2.6	3.1	3.6	4.3	-10	3	7	13	38

Table 1. Projected climate change in East Africa by the end of the 21st century [7]

With regard to temperature there is a clear consensus across all models that temperatures *will* increase, although the predicted range is quite large and, agriculturally speaking, very important. A rise in mean temperatures of over 4°C by 2100 would have very different and much more dramatic impacts than an increase of less than 2°C. The clear consensus that we *are* living in a warming world has been widely confirmed through trend analyses of long-term historical daily temperature records both worldwide and in SSA. This is useful in that

it provides a clear framework within which research into adaptation strategies to deal with increasing temperatures can be framed with some degree of confidence.

For rainfall, the picture is less clear with some models, for example, projecting quite severe drying in Eastern Africa in different three monthly periods and others projecting substantial wetting. However, monthly periods in which the middle half (25–75% quartiles) of the model projection distribution is of the same sign are coloured red in Table 1 and point to an emerging consensus that for both the short rains (OND) and the long rains (MAM) in East Africa, the probability is that it will become wetter over time due to an increased frequency of El Niño type events.

However, unlike the confirmation provided by trend analyses of historical weather data for temperature increases, corresponding analyses for changes in rainfall totals and distribution patterns do not currently confirm such a wetting trend in East Africa and complimentary evidence from recent publications on the impact of climate change on food security is often conflicting, for example:

- In [11] it is concluded that Eastern Africa is 'largely insulated' from the impacts of climate change with temperatures only rising by 1°C by 2030 and in general, rainfall increasing by 7 to 9% with a corresponding increase in the length of the growing season in many parts [12].
- In contrast, in an analysis of East African rainfall data, [13] suggest a decline in the long rains (MAM) in Eastern Africa which they attribute to increases in the Indian Ocean sea surface temperature, thus threatening future food security, but …
- A trend analyses of the long rains precipitation covering the same time period undertaken for five locations in Kenya [14] and one location in Uganda [15] failed to identify any such drying or indeed wetting trends.

A further additional source of uncertainty is introduced when downscaling techniques are used to try to give "better" regional projection of climate, in other words information below the grid scale of the AOGCM. These techniques include the use of sophisticated statistical methods, such as regression type models and weather generators, and also dynamical based methods such as high resolution climate models to represent global or regional sub-domains. These techniques have been used with varied degree of success. For example, [7], Chapter 11 assesses these approaches and conclude that "*downscaling methods have matured since the Third Assessment Report* [16] *and have been more widely applied, although only in some regions has large-scale coordination of multi-model downscaling of climate change simulations been achieved*." In [17], a review of downscaling methodologies for Africa Climate applications was presented. They concluded that "*downscaling is best understood as an attempt to increase the understanding of climate change influences at the regional scale. In that context, a variety of methodologies should be explored, using all tools possible to increase that understanding*"

In summary therefore, from the outset, researchers are faced with the following challenges:

- To date, even in the absence of climate change, the development of the diverse rainfed agricultural systems in Africa has been disappointing. The low adoption of innovative

farming practice has been constrained, not only by the lack of enabling policies and infrastructure, but also by the current large season to season and within season variability of rainfall distribution and the resultant risk that it poses for farm level performance and hence for returns to investment in this sector.

- Regional level projections from AOGCMs have provided a strong consensus that temperatures will increase considerably by the end of this century and this is reflected in the analyses of long-term historical temperature records both globally and within SSA.
- Similar AOGCM projections for rainfall changes are not so clear but consensus pictures are emerging. For example, in Eastern Africa, a consensus has emerged that it will become wetter in both the short and long rainy seasons. However, unlike with temperature, these wetting trends are not yet evident in the analyses of long-term historical rainfall data and published evidence of such trends is both scarce and can be contradictory.
- The use of downscaling approaches adds another layer of uncertainty to future climate projections.

3. Meeting the research challenge: a two-pronged approach

Given the constraints noted above of (i) current climate-induced risk and (ii) the predicted (although uncertain) future change in the nature of that risk due to climate change, it is now widely accepted that a two-pronged approach, sometimes referred to as the 'twin pillars' of adaptation to climate change, is needed [18, 19, 20, 6]. Such an approach recognizes that both short and medium to long-term strategies are required:

- **Coping Strategies** are those that have evolved over time through farmers' long experience in dealing with the current known and understood natural variation in weather that they expect both within and between seasons, whereas:
- **Adaptation Strategies** are longer-term (beyond a single rainfall season) strategies that will be needed for farmers to respond to a new set of evolving climatic conditions that they have not previously experienced.

In undertaking research to elucidate farmers' possible adaptation strategies, such strategies are often confused with farmers' traditional coping strategies. In the context of addressing climate-induced risk more generally, research on both is useful, but the confusion between coping and adaptation inevitably devalues the research and could well lead to erroneous recommendations.

3.1. Short-term: Coping better with current weather-induced risk to farm production

Firstly in the shorter term, since rainfed farmers are already vulnerable to current weather variability and associated shocks, it is essential to help them to build their livelihood resilience through coping better with current climate-induced risk as a pre-requisite to

adapting to future climate change. Not only will greater resilience, and hence a greater adaptive capacity, allow farmers a wider range of adaptation options in the future, but perhaps more important is the consideration of the already substantial current season-to-season weather ranges and the extent to which these ranges will, or will not change in the future. Whilst temperatures are already increasing and changes in rainfall amounts and patterns may begin to become clearer in the future, the question remains to what extent will farmers experience conditions under progressive climate change that they are not already experiencing today?

In [21], an example based on an analysis of the impact of an assumed 3°C rise in temperature on the length of growing period (LGP) at a semi-arid location in Kenya (Figure 2) is provided. Whilst a possible 3°C increase in temperature in the future reduced the mean LGP by about 8% across the 45 years analyzed, the projected LGPs ranged from 63 to 152 days compared with the 76 to 175 experienced today. In other words, in about 80% of the seasons that would occur in the future under the assumed 3°C temperature increase, farmers would *still* be experiencing similar LGPs to those that they are already experiencing today.

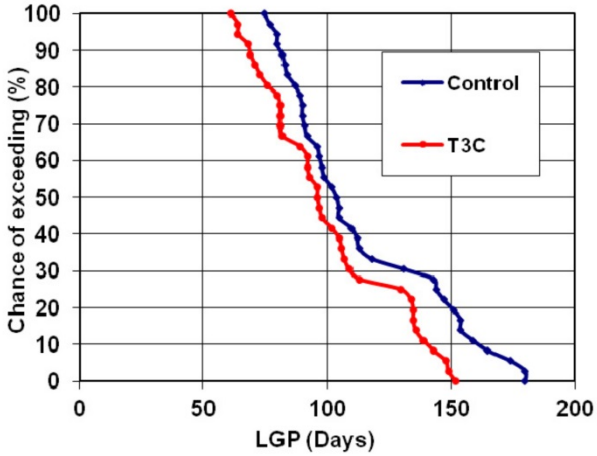

Figure 2. The effect of a 3°C rise in temperature on the Length of Growing Period (LGP) at Makindu, Kenya. 1959-2004 [21]

In conclusion, helping farmers cope better with current climate variability is a win-win situation. It will improve their lives now and help in the future.

3.2. Medium to longer-term: Adapting agriculture to future climate change

In the medium to longer term and as climate change becomes more obvious, both in its identification and impact, farmers will have to adapt their farming practices to a new set of weather-induced risks and opportunities. However, there are three major complicating factors in this second aspect of the strategy:

i. We have already referred to the uncertainty associated with future climate projections and the new nature of the climate that farmers will need to be adapting to. In other words, the 'climate change goal posts' for which research should be aiming are uncertain. That in itself poses considerable research questions.

ii. This is further complicated by the fact that climate change will be progressive over time and the length of time it will take before a '*final climate state*' is achieved (if indeed it is achieved) is unknown. In other words – the goal posts will be continually moving with time! This infers that climate change adaptation research itself has to be ongoing and continually self-assessing.

iii. We have already mentioned the natural and characteristic variability of rainfall in the region, both within and between seasons. Drying and wetting cycles are a natural characteristic of this variability and can be quite lengthy as at Bulawayo in Zimbabwe (Figure 3), but usually are somewhat shorter, 3 to 4 years in duration (see Figure 6). This characteristic of the climate itself imposes the caveat that one should be careful not to mistake such relatively short term trends for long-term climate change. But that in itself begs the question *"how does one know whether a currently observed trend is short term or the start of longer term climate change?"* In Kenya for example, there have recently been a series of drier than normal seasons. Is this just another short term drying trend as has been observed before or the start of a longer process of climate change as many currently seem to assume?

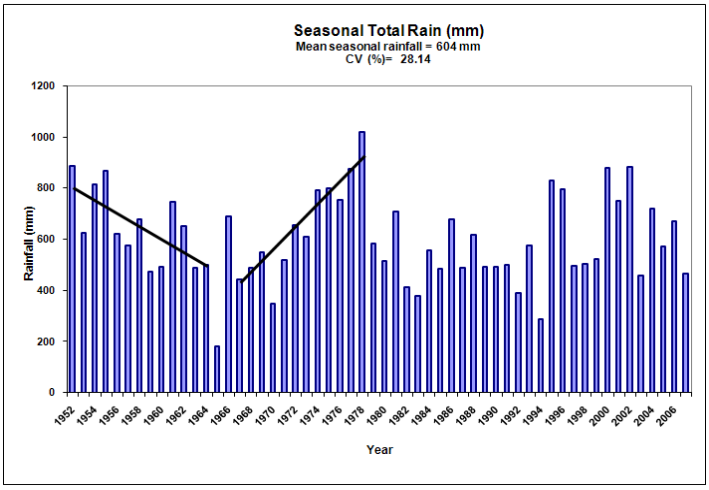

Figure 3. Relatively long term (10 year) drying and wetting cycles at Bulawayo, Zimbabwe (1952-2007).

4. Supporting evidence-based climate adaptation strategies: The foundation stones of success

In spite of the challenges illustrated in Section 2 and the complexities of short-term versus medium to long-term approach to adaptation highlighted in Section 3, the agricultural

research community does urgently need to initiate research now to identify medium to longer term climate adaptation options for the future. *What are the key elements that need to be put in place for the research community in Africa to undertake research into climate adaptation and be able to provide evidence-based adaptation options to farmers?*

The observations and conclusions described in this study are not the outputs of a formalized research approach or specific experimental design. They are based on the long-term, substantive and collective experience of the authors who have interacted for many years with a wide range of projects addressing the challenges of both current climatic variability as well as future climate change impacts on rainfed agricultural production and farmer livelihood. Such interactions have arisen through a range of circumstances from (i) living and working at agricultural institutions based in SSA, (ii) working for advanced research institutions that have partnered with African institutions addressing climate variability and change impacts to (iii) providing extensive training and support for African researchers to enable them to acquire the scientific skills required to undertake such research.

Most recently, since 2010, the authors have worked together as a team within a project supported by the Rockefeller Foundation through a grant to the Walker Institute for Climate System Research at the University of Reading, UK, entitled '*Supporting the Rockefeller Foundation Climate Change Units (CCU) in East and Central Africa'*. As part of that grant, Rockefeller asked the authors to address the question of '*What would success look like?*' with regard to their support to eight CCUs in Tanzania, Kenya, Rwanda, Uganda and Ethiopia.

The authors highlight here what they believe are the most important 'foundation stones' upon which rigorous and useful climate change research should be built, and in this context, research that addresses both aspects of the 'twin pillars of adaptation' to climate change, as discussed in Section 3, is included. These foundation stones are summarised in Table 2 according to the three groupings of (i) Improved access to information, (ii) Enhanced research capacity and (iii) Enhancing the impacts of research.

Improved access to information	**Enhanced research capacity**	**Enhancing the impacts of research**
Access to literature and a database of projects	*Developing conceptual frameworks for the impact pathways of change*	*Producing quality **written** publications to influence stakeholders*
Access to historical climate data	*Risk and trend analyses of historical weather data*	*Producing **visual** presentations to influence audiences*
Access to up-to-date curriculum in Universities	*Analyses of impacts of climate variability and change on agricultural production*	*Archiving primary data in accessible formats*

Table 2. Foundation stones upon which rigorous climate change research should be built.

4.1. Improved access to information

Most of the scientists currently engaged in climate change research in the area have been trained in various disciplines of agriculture or the social sciences but do not have a fundamental knowledge of the climate sciences. Yet the onus is upon them to plan and execute relevant and innovative research targeted towards helping farmers cope better with current climate-induced risk and to adapt to climate change. For them to successfully address this challenge, it is imperative that they have easy access to:

- Published and unpublished information contained in the literature that is related to their field of enquiry.
- Information about both completed and on-going projects addressing climate risk management and adaptation to climate change in SSA, and
- Long-term daily weather datasets collected from recording stations close to the location where their studies will be based, without which 'hard' climate risk and climate change research is very difficult, or indeed, near impossible.

Without access to such information there is a real danger that the research undertaken will fail to be well prioritized, rigorous, relevant and non-repetitive of that already undertaken or currently on-going.

In addition, it is equally, if not more important that the next generation of scientists who undertake such research will have had a much more substantive exposure to climate science in their graduate and postgraduate training than is currently the case. This will require the building of specific and up-to-date teaching material into their curricula.

4.1.1. Access to literature and a database of projects

Over the last four to five decades, a great deal of research has been conducted in East Africa and across SSA. Much of this is relevant to the first of the twin pillars of adaptation, namely that of helping farmers cope better with current climate-induced risk. Indeed, research that has specifically studied farmers' weather driven coping strategies has been on-going in Africa for twenty or more years [22]. More recently, and of direct relevance to the second of the twin pillars, namely helping farmers to adapt to climate change, much has also been reported on climate change projections in SSA and their possible impacts on rainfed agriculture and food security.

In East Africa for example, the impacts of climate change projections on the length of the growing season have been examined by [12] and more recently, on food security, by [11] and have also been reviewed by [23]. In [24] a regional climate model to compare the effects of projected greenhouse gases concentration and land use land cover change on spatial variation of crop yields in East Africa has been used. In addition, the extent to which projected rainfall and temperature trends are, or are not, yet becoming evident in daily and seasonal weather observations have also been assessed [13, 15, 14].

The authors have found that when supporting scientists in developing their research proposals to address current climate risk and future climate change, almost all the them had

trouble in accessing published information that is relevant to their proposed research. In particular, it is apparent that many do not have access to the literature reporting climate change projections for their region [7] or individual papers assessed by the IPCC. Hence they undertake their research in the absence of an understanding of the emerging consensus as to likely future climates in their regions to which farming families will have to adapt.

Such projections can be obtained as coarse resolution outputs of the global climate models (GCMs) from the Intergovernmental Panel on Climate Change (IPCC) data portal [25] and finer resolution downscaled data can be downloaded from the Decision and Policy Analysis Program of the International Centre for Tropical Agriculture (CIAT) website [26].

However, in spite of the relatively easy access to available literature, it remains quite common for the research problem to be defined and the objectives and activities detailed with very little, or indeed any, literature review having been undertaken. In such cases, 'undertaking a literature review' is often stated as one of the objectives or activities. Clearly, it is not ideal to first prescribe the research to be undertaken and then undertake a literature review to find out what has already been done and what is already known.

In some respects, this lack of access to published material is understandable, but in the age of the web and Google Scholar, much more literature searching should have been possible. In addition, SSA is fortunate to have many international research bodies with their offices based in African countries. For example in East Africa, the Office of the IGAD Climate Prediction and Applications Centre (ICPAC) are in Nairobi, Kenya as well as several relevant international centres (e.g. ILRI, ICRAF, CIMMYT, ICRISAT, CIAT, and CABI). All these centres are involved in climate risk management research and have much published and unpublished information available which can be easily accessed through a visit. In addition, many of the African universities and research institutions have well stocked libraries which can also be visited. However, this could be difficult for many scientists who are based some distance from a research headquarters or university or do not have easy access to the internet. *In that respect, a dedicated review of the literature and the production of an easily accessible annotated bibliography of up-to-date and key climate risk management and adaptation literature would be very helpful to many scientists.*

Finally, there are a large number of completed and ongoing climate related research initiatives, many of which are supported with external funding. Such initiatives have an enormous range of scales at which they operate. Whilst some are quite modest in both scale and funding support, others are very large, region wide in scope and long-term in duration. The Climate Change, Agriculture and Food Security (CCAFS) [27] initiative, active in both West and East Africa is probably the single biggest example. The CCAFS Research Programme is founded on the principle of sharing of methods, data and publications. What however is of great concern is the lack of information, or at least the sharing of information, concerning the existence, scope, activities and results obtained by past and on-going projects that are addressing climate risk and adaptation to climate change. This problem appears to exist across regions, countries, institutions, funding agencies and even within institutions themselves. Indeed, within the Rockefeller initiative, several grant recipients have found it

necessary to produce a database of climate related projects within their own institution in order to better understand the scope of their own past and on-going climate related research.

Given the real danger of precious financial resources being used to support research that has already been undertaken, or is on-going elsewhere in SSA, it is very important that, at least on a regional basis, the information held by individual institutions and funding agencies is collated, made easily accessible and shared more widely.

4.1.2. Access to historical climate data

A great deal of daily weather data has been collected in each country of SSA over the last 60 to 70 years and indeed some records go back more than a 100 years [28]. The network of recording stations is not very dense but this information is fundamental to climate risk and climate change research. Easy access to high quality long-term daily weather records is essential to:

- Undertake detailed risk analyses of important weather events that affect crop and livestock performance and assess to what extent there are or are not significant trends in those parameters that could be ascribed to climate change [29].
- Compare widely held perceptions of climate change, often documented in farmer surveys, with the realities of long-term daily weather data analyses [14,15].
- Drive a range of hydrological models as in [30] and crop growth simulation models as in [21,31] which integrate the impacts of rainfall, temperature and solar radiation variability into expressions of agricultural and environmental risk response.

Whilst it is true that a new generation of weather generators (for example MarkSim and Weatherman) can produce long-term weather datasets that are mathematically and statistically representative of real time weather data for any given location and can be used effectively to drive agricultural models (e.g. [31]), they can only ever be a first approximation for estimating climate-induced production risk and cannot be used to assess possible trends in important climatic parameters.

However, in spite of the evident importance of national scientists being allowed easy access to such national datasets, this is not the case in most countries in SSA where the National Meteorological Services (NMS) require payment for the datasets and even when this can be afforded, the data provided is often of poor quality and limited duration.

This constraint is well known and many individuals and institutions are now engaging with the NMS. In the context of climate-induced risk in the vital sector of rainfed agriculture and the possible impacts of climate change in exacerbating those risks, such data are too important to be considered the property of a single entity and should be declared national public goods. Indeed, [32] concluded a seminal review of the potential of seasonal climate forecasting in SSA with the recommendation *"Finally, meteorological data [in sub-Saharan Africa] should be treated by national policy as a free public good and a resource for sustainable development across sectors"*.

Engagement with the NMS by funding agencies, influential scientists and global organizations such as the World Meteorological Organization (WMO) would pay dividends. While it is clear that NMSs need to cover their costs of data collection, they should also be able to position themselves to generate even greater resources from offering innovative, demand-driven, value added weather products to the agricultural community.

However, it must also be recognized that the sharing of raw data in collaborative partnerships between universities, National Agricultural Research Institutions and NMS must be a "two way street". It is important that credit be given to the NMS for the considerable efforts they make to computerise and quality-control their historical records. Were they to agree to an exchange of their records for similar long records of yield and growth data from agricultural research scientists, they would probably find many researchers equally unwilling to share their own data. Sometimes such sharing would expose the poor strategies for quality control of the agricultural datasets and it might even be that they are unavailable, since a great deal of data remain with students, or staff who have left the institute. And this is often despite the use of public funds for the research.

Since the 1980s, and led partly by the World Meteorological Organisation (WMO), the climatic community has devoted considerable resources to the management and quality control of the long-term historical records. This has yet to be matched by the agricultural research initiatives. It is important that funding agencies who support climate adaptation research help to ensure that primary datasets that are developed using their funds are well organised during the research period and made publically available once the researchers have completed their work.

4.1.3. Access to up-to-date curriculum in universities

The evidence from analyses of long-term temperature data is unequivocal in demonstrating that the world is warming at an unprecedented rate, and whilst parallel analyses of rainfall records as yet seldom show significant trends, there is little doubt that such trends will become progressively apparent in the coming years. Simply put, over time the impacts of climate change will increasingly be felt in the agricultural sector and indeed across all sectors in SSA. In response to this, it is important that the next generation of agricultural scientists, both undergraduates and postgraduates, have a far stronger grounding in the climate sciences and a far greater understanding of the interactions between climate, people and agriculture than is currently the case.

Globally, many universities are offering appropriate courses at the graduate and postgraduate level and the opportunity for African students to register for such courses will remain available providing the funding is available to support them. However, the number of students who can benefit this way will always be limited and is unlikely to create the critical mass of expertise that will be required in the future. What is needed is the universities of SSA themselves to develop well structured, targeted and up-to-date curricula. To some extent, this can be achieved by individual universities assembling existing and relevant modules from a range of different degree courses and building them into a more dedicated and structured course. However, this approach is unlikely to provide

an optimal solution for two reasons. Firstly, *within* any given university, existing modules are unlikely to cover the full scope of the climate change agenda that is required and the modules that do exist will possibly be of different quality. Secondly such modules were probably designed to address the needs of specific courses rather than to be integrated into a comprehensive teaching agenda addressing agriculture, climate risk and climate change.

A better solution would be achieved through greater interaction and discussion *between* universities in SSA to (i) agree on the essential topics that would need to be included in comprehensive graduate and postgraduate climate related courses, (ii) assess what material is currently "at hand" both within and from outside SSA and (iii) build the best of that material into a comprehensive and integrated agenda of adaption to and mitigation of climate change. In addition, universities would need to asses to what extent the staff responsible for the teaching of such a course would require some specialized training in its delivery.

Training is also urgently needed for the current generation who are working in a wide range of climate related research and development projects. These include not only researchers, but also agricultural extension staff, NGOs and farmer's organizations, all of whom need to understand the 'twin pillars of adaptation' described earlier. Currently all these organizations and farmers themselves are acutely aware of the general topic of "climate-induced risk and change", but all too often they struggle to find the most useful way to respond.

Where funding agencies do support the development of new curricula together with the corresponding training material, they should also ensure that the resulting materials are "open educational resources" in order to ensure their widest possible use.

Given the great importance of establishing a critical mass of 'climate informed' research personnel for the future, it is important that initiatives to develop a comprehensive climate change curriculum are considered a priority and are provided with funding to support their initiation and implementation.

4.2. Enhanced research capacity

An increasing number of projects are being funded to undertake research that will investigate ways in which the negative impacts of climate change on rainfed agriculture in SSA can be mitigated. As mentioned in the previous section, the majority of agricultural scientists engaged in this research have little, if any, background training in climate science. Given this, it is not surprising that many are not aware of the complexities of the climate science that underpin climate change projections or the associated uncertainties and the challenges inherent in climate change adaptation.

None of this is surprising, nor is it unique to scientists in SSA, but it does reinforce the idea that current initiatives aimed at improving the climate change curricula has a very high priority as has the continued capacity enhancement of those who are already involved in such research. Through visiting and working together with the researchers in East Africa

over the last 18 months, the authors have identified three areas where immediate priority should be given in capacity development, namely:

- Developing conceptual frameworks for the impact pathways of change
- Risk and trend analyses of historical weather data
- Analyses of impacts of climate variability and projected climate changes on agricultural production.

4.2.1. Developing conceptual frameworks for the impact pathways of change

Over the last decade, climate change has become one of the hottest topics across SSA. It is being discussed across all levels of society from high-level government representatives, representatives of national and regional bodies, to research and development agencies and through to private citizens and to small-scale farmers.

However, investigations into the possible current and future impacts of climate change need to be put into the context of the well documented and on-going impacts of other drivers of change, some of which are currently likely to be of more immediate importance than climate change itself.

Without doubt, population growth is the single greatest primary driver of change in many parts of the world and particularly in SSA. Indeed, globally, it is the primary driver behind increased greenhouse gas emissions and hence climate change.

In East Africa for example (Table 3), between 1961 and 2011, the population (Ethiopia and Somalia excluded[1]) has risen from 49 to 208 million people, and is projected to rise to over 500 million by 2050. The direct impact of this is most clearly illustrated by considering the number of additional people that have to be fed each year without there being the opportunity to greatly expand the area of high potential land available for agriculture. In the ten years leading up to 2011, there was a mean of (excluding Ethiopia and Somalia) 4.4 million additional mouths to feed *each year*, and this is projected to rise to a mean 8.8 million additional mouths to feed *each year* in the 20 years leading up to 2050. That in itself presents, and will continue to present, enormous challenges for policy formulation and agricultural development.

Over and above that direct consequence, there are a range of 'secondary' drivers of change that have stemmed from population growth. Whilst the impact of some of these 'secondary' drivers of change on agriculture have been positive, such as the creation of new markets, increased demand for crop and livestock products and greater opportunities for off-farm employment, almost all the impacts of population pressure on rural communities, agriculture and the environment have been negative and are likely to become worse in the future.

Therefore, it is essential to formulate a clear 'climate change' hypothesis in any research project and then situate that hypothesis in a conceptual framework that considered the

[1] NOTE: statistics for Ethiopia are not available for the full period, but in 2011 the population stood at 85 million and is projected to rise to 145 million by 2050. No statistics are available for Somalia.

	1961	1971	1991	2011	*2031*	*2050*
Burundi	3.0	3.6	5.7	8.6	*11.6*	*13.7*
Kenya	8.4	11.7	24.2	41.6	*67.4*	*96.9*
Madagascar	5.3	6.7	11.6	21.3	*36.2*	*53.6*
Rwanda	2.9	3.9	6.9	10.9	*18.0*	*26.0*
Sudan	11.8	15.2	27.2	44.6	*68.1*	*91.0*
Uganda	7.0	9.7	18.3	34.5	*61.1*	*94.3*
Tanzania	10.4	14.0	26.3	46.2	*84.2*	*138.3*
TOTAL	48.8	64.8	120.2	207.7	*346.6*	*513.8*
Additional people to feed *each year (millions)* (Mean for time period)	-	1.6	2.8	4.4	*6.9*	*8.8*

Table 3. Actual and *projected* human population trends in selected East African countries (millions) Source FAOSTAT

possible impact pathways of other drivers of change. For example, one could base their study on the hypothesis that 'climate change was leading to a decline in rainfall and was responsible for an increase over time of the number of people and livestock suffering food and feed shortages'. A conceptual framework that situates this hypothesis in the context of related impact pathways of human and animal population growth can be developed (Figure 4).

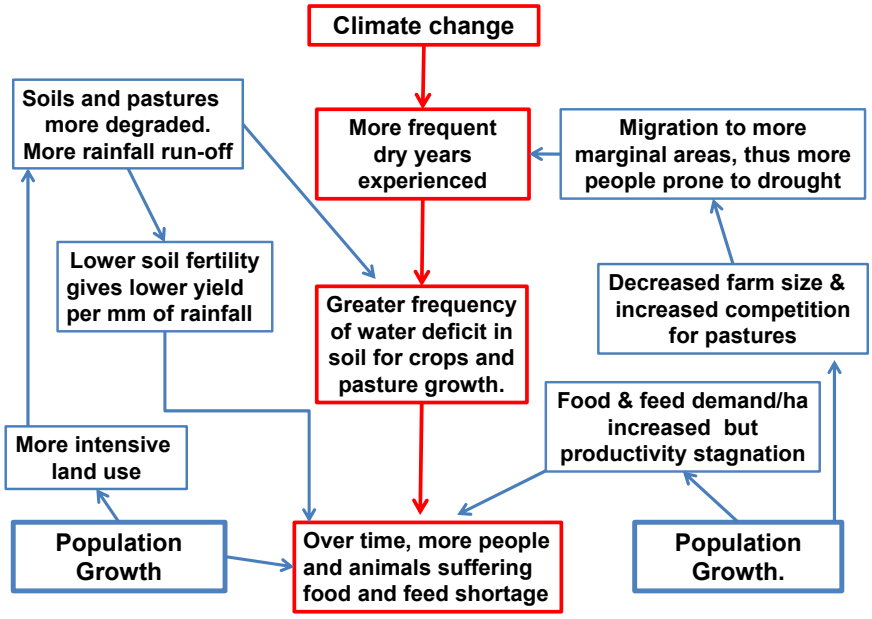

Figure 4. Illustrative impact pathways of climate change (red) and population growth (blue).

Unless researchers are trained to undertake this type of thinking process, misinterpretation of results could lead to quite serious consequences. For example, in the studies by [14, 15], survey work indicated that farmers believed that declining rainfall was responsible for lower crop yields and farm productivity. Taken at face value, such a conclusion could well have led to initiatives to identify appropriate adaptation strategies for drier conditions such as moisture conservation practices or the use of shorter duration crop varieties. This would have been a serious mistake since in each case further investigation showed that other drivers of change were responsible for declining productivity, and not declining rainfall resulting from climate change.

Putting climate change in the context of other drivers of change is essential for researchers to have confidence that the processes, impacts and research innovations under investigation are properly focussed on climate-induced risk and change and are not in response to other drivers of change.

4.2.2. Risk and trend analyses of historical weather data

Section 4.1.2 discussed the importance of access to high quality long-term daily weather data and indicated the value of such data in enabling climate risk analyses and trend analyses. Both types of analyses are important.

Risk analysis: Rainfed crop growth, development and yield formation can be greatly influenced by individual weather events or by a combination of events. Such events could include for example (a) a series of rainy days at the start of the season that enables planting, (b) a period of drought following planting which leads to seedling death, (c) very heavy rain that causes water logging and impairs root growth or signals the possible onset of root diseases such as root rot in beans, (d) below optimal rainfall or super-optimal temperatures at flowering resulting in poor yield formation or (e) terminal drought resulting in poor grain filling or the possible onset of disease outbreaks such as aflotoxin in groundnuts.

Risk analyses of long-term daily weather data can assess the probability (or risk) of such events occurring and can assess how that risk can be 'beneficially managed' through, for example, the choice of planting date or the choice of crop varieties of different maturity lengths, or even the choice of different crops. Examples of such analyses has been undertaken and published by several authors from the 1980's onwards and most recently by [29] who used eighty-nine years of daily rainfall data from Moorings recording station in Southern Zambia as a case study in which a range of agriculturally important weather events such as those above were investigated using the statistical software Instat [33] and Genstat [34] as well as a simple water balance model [35].

One example they gave addressed an issue that is always a widespread priority concern of rain-fed farmers, namely, '*when has the rainy season started and when is it 'safe' to sow their crops'*? The example given stemmed from discussions with farmers near to the recording station which had indicated that in general, they tended to plant their maize as soon after mid-November as possible, but required that at least 20mm of rain had fallen within a 3-day period before they would do so. They also indicated that if there was a 10-day dry period in

the month following planting, then maize seedling death occurred, necessitating re-planting. The results of the analyses are given in Figure 5 which shows the date, according to the farmers' criteria, when the first planting took place each year and in which of those years a dry spell occurred that necessitated re-planting. There are 12 such occasions in the 88 years, indicating that the risk of not succeeding with early planting was about 14%. If the dry-spell following planting condition is changed to 12 days length, (not shown) then the risk dropped to 8 years in the 88, or about 9%. This indicates the improvement that might be achieved with a more drought tolerant crop, or with simple moisture conservation measures to reduce soil surface evaporation losses such as soil surface mulching.

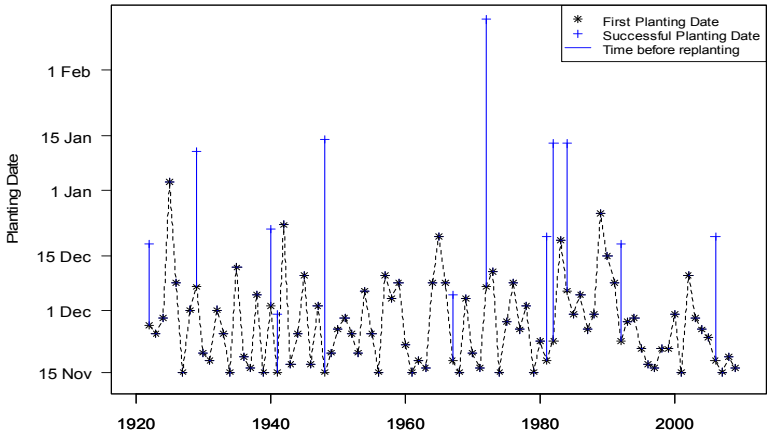

Figure 5. Date of the start of the rain, at Moorings, Zambia from 1922 to 2009 [29]

Such types of analyses provide a valuable additional source of *ex ante* risk information that will help prioritize what field-based investigations need to be undertaken.

Trend analyses: Given the uncertainties of climate change projections (see Section 2) and the fact that such uncertainties become greater as smaller time and spatial scales are desired, trend analyses of existing long-term historical climate data can be considered as '*the gold standard*' of assessing the extent of current climate change at locations where adaptation research is being undertaken [36].

It is important for two reasons:

- Firstly, using appropriate statistical curve fitting approaches to long-term data sets helps avoid the danger of mistaking short term trends of a few seasons with long-term climate change. Such cycles can be relatively long-term (see Figure 3 for Bulawayo, Zimbabwe) or shorter term as illustrated for total seasonal rainfall at Makindu in Kenya (Figure 6) where the short term wetting and drying cycles are apparent (e.g. 1963-1966, 1974-1978, 2000-2004), but fitting a line to the complete dataset showed no significant trend in either direction. This is in contrast to fitting curves to the maximum and minimum temperature data from the same location (Figure 7). Whilst the same sort of season-to-season variability in temperature is noted, fitting a curve to the complete dataset *did* show a significant increase in both maximum and minimum temperature.

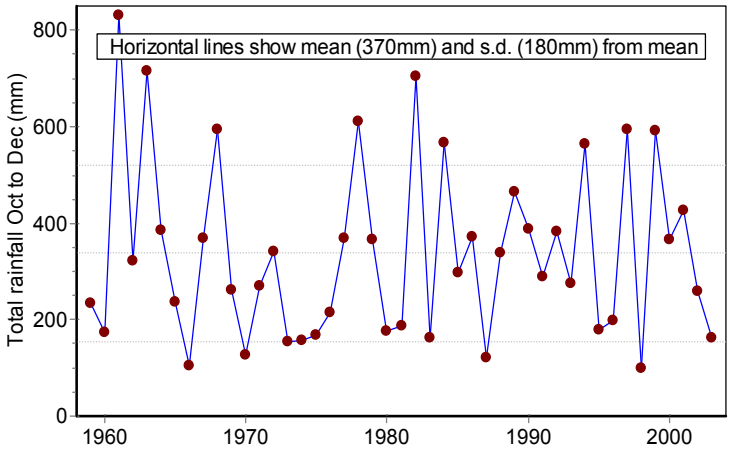

Figure 6. Seasonal (OND) total rainfall at Makindu, Kenya (1954-2004) [23]

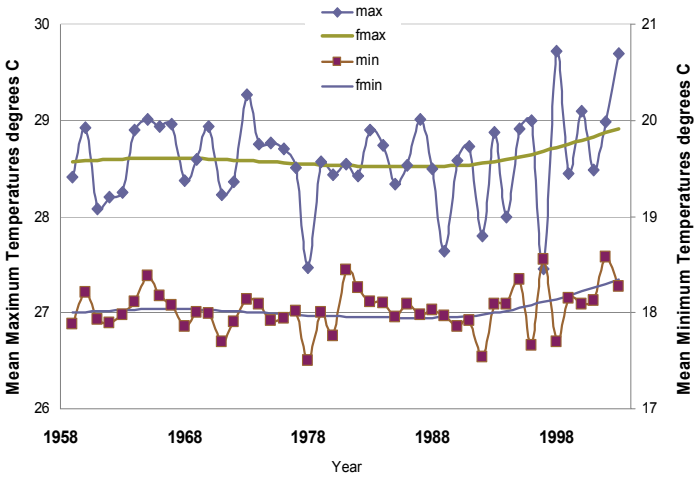

Figure 7. Seasonal (OND) mean maximum and minimum temperatures at Makindu, Kenya (1959-2004) [23]

- Secondly, a great deal of research currently underway within SSA is centred on survey work that investigates farmers' perceptions of climate risk and possible climate change and their associated coping and adaptation strategies. Having long-term weather data at hand to compare farmers' perceptions with the 'hard' risk and trend analyses of recorded weather data can be invaluable in identifying to what extent they are correct or indeed whether perhaps they are responding to other drivers of change. This is exactly what happened in the studies in semi-arid Kenya by [14]. Farmers perceived that climate change had caused declining rainfall amounts since the early 1990's and which they felt had resulted in declining maize yields. However, trend analyses of the long-term historical rainfall data from 5 locations in the study area showed no decline in rainfall amounts or changes in their distribution patterns. Further studies, whilst confirming that district level yields had indeed declined as perceived by farmers, showed that this was due to (i) a reduction in fertilizer use as a result of an increase in its price following structural readjustment during the 1990's, and (ii) migration of farmers to land with a lower yield potential due to population pressure. It was not due to climate change.

To be able to perform climate risks analysis and trend analysis of any long-term data record, the use of statistical packages is imperative for researches to be able to produce real evidence of change and hence be able to give evidence based advice.

Given the importance of this type of analysis for climate change adaptation research, the need for training on statistics in applied climatology is essential.

4.2.3. Analyses of impacts of climate variability and change on agricultural production

In addition to the type of climatic analyses described above, a further step can be taken by using a range of models to analyze the impacts of variable weather on many aspects of agricultural production, including crop, livestock, pastures and trees and shrubs using simulation models. Clearly, such models are an important tool for researchers to use if they are interested in assessing the integrated impacts of different components of climate variability (principally rainfall, temperature and solar radiation) and climate change on rainfed agricultural production.

Globally, a large number of such models have been developed. They demonstrate an equally wide range of characteristics that embrace different aspects of agriculture (i.e. crops, livestock, pastures, trees), the spatial scale at which the model operates (i.e. from plot level → farm → water catchment) and the complexity of inputs that are required to calibrate the model for the purpose the researcher has in mind. For example some models require daily weather values for rainfall, temperature and solar radiation whilst others can run with monthly means and totals. In [23] an illustrative and descriptive list of such models (and the web address where more information can be found) is provided. Because the output of such models is dependent on the climate, soil, crop, pasture and livestock management input information that the researcher provides, they can be used to complement field-based research by providing an *ex ante* evaluation of the effectiveness of any given intervention across a wider range of conditions and over a longer period of time than is usually possible through field-based research alone. This provides an additional and important source of information to that obtained from field trials when researchers are required to formulate recommendations for policy makers' consideration.

Two of the most widely used crop models are the Decision Support System for Agricultural Technology (DSSAT) and the Agricultural Production Systems Simulator (APSIM). These models *integrate* the impact of variable daily weather (principally rainfall, temperature and solar radiation) with a range of soil, water and crop management choices. Since they are 'driven' by daily weather data, they can be used to assess the impact of season-to-season climate variability on the risk associated with a range of agronomic strategies for a wide range of crops, trees and pasture that are important to African farmers. When properly calibrated they can provide an impressively accurate simulation of what occurs in 'real life'. An example of their power is illustrated in the study by [31] who used APSIM and 50 years of daily weather data from Kitale, Kenya to investigated the effect of a factorial combination of weed control (2 levels), seeding rate (6 levels) and N-fertilizer application (8 levels) on the

growth and yield of maize – *equivalent to running a trial of 96 treatments for 50 years!* When compared with the data produced from an intensive agronomic investigation undertaken at Kitale nearly 40 years ago [37], the simulations produced by APSIM closely mirrored the agronomic responses observed by [31] (Figure 8). Perhaps more important is the fact that such simulations using long-term weather data can provide a more comprehensive assessment of climate-induced risks than is usually possible to achieve through field-based research which is inevitably constrained both by expense and by the length of time such studies can be continued.

Calibrating these types of models for different soil types and different crops and crop varieties is not a trivial exercise, and they do need some careful training and some follow-up support until the user becomes familiar with their use. However, once they are properly calibrated and the skills to use them are mastered, they are very powerful tools indeed for investigating climate-induced production risk associated with a broad range of possible interventions.

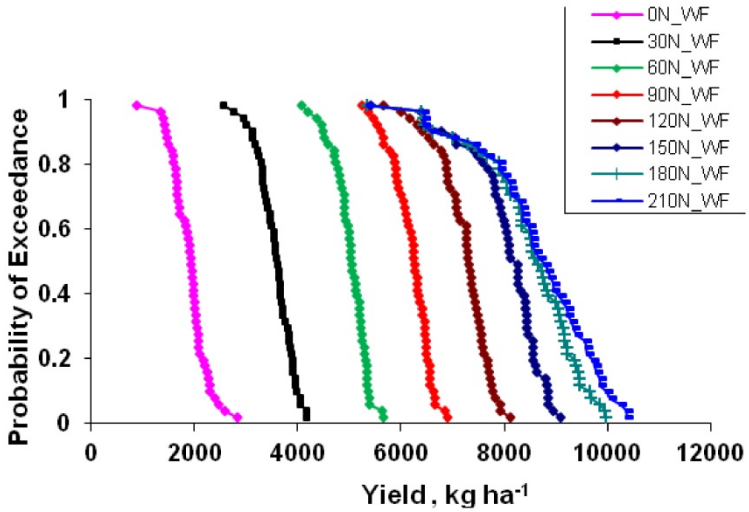

Figure 8. Probability distribution of simulated (APSIM) maize yields at different fertilizer levels (kg N ha^{-1}) in weed free (WF) maize at Kitale, Kenya [31]

Moreover and importantly, they are equally powerful in simulating the impacts of possible changes in CO_2 levels and temperature and rainfall regimes that could result from a range of climate change scenarios. Figure 9 provides an example of such an analysis where the disaggregated and aggregated impact of a climate changes [7] for Southern Africa were examined, namely:

i. CO_2 increased from 350 to 700 ppm,
ii. Temperature increased by 3°C and
iii. Rainfall decreased by 10%
iv. Combined effect of (i), (ii) & (iii)

These scenarios were compared with the baseline simulation of 'today's climate' for a well managed crop of groundnuts at Bulawayo in Zimbabwe using 56 years of daily weather data [21].

Earlier, cost was one limitation in the use of these software packages. Recently, a welcome change is that the developers of both APSIM and DSSAT have decided that researchers may have access to their software at no financial cost.

Given the value of simulation models funding agencies might consider providing dedicated funding to support learning and capacity enhancement in their use.

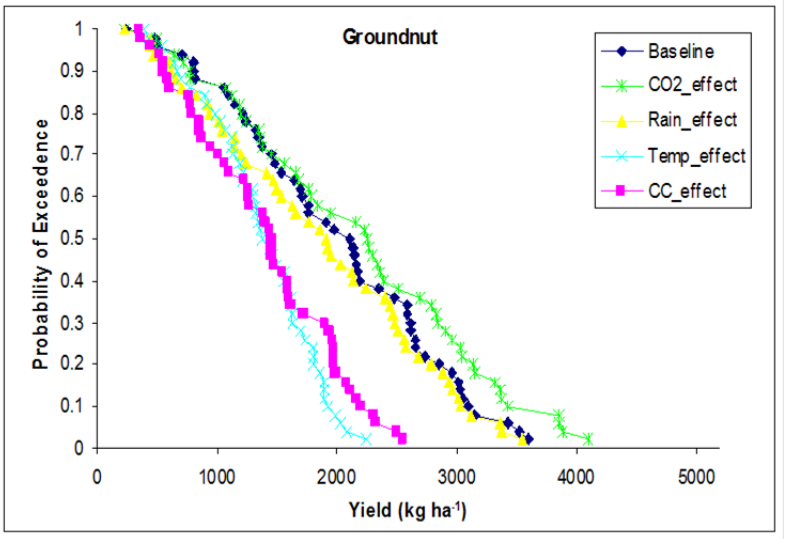

Figure 9. The probability distribution of the disaggregated impact of simulated (APSIM) climate change on the yield of groundnut compared with today's baseline climate. Bulawayo, Zimbabwe. [21]

However, organisations sometimes use training opportunities more as a way of rewarding staff, rather than to change the working practices of individuals and organizations as part of a planned capacity enhancement strategy. *It is suggested that proposals that include capacity-building should recognise that evaluation of the training components will be based on changed working practices of the trainees and of the organisation itself* [38]. The satisfaction and learning of the participants in the training courses is necessary, but is not a sufficient reason for including a training component.

4.3. Enhancing the impacts of research

If the six foundation stones discussed above under *'Improved access to information'* and '*Enhanced research capacity*' are in place within the region, then there is a strong likelihood that the quality, relevance, analyses and outputs of the work will be greatly improved. But the job does not end there. If those research results are to have the desired impacts on the welfare of rain-fed farming families, it then becomes even more important that the outputs of the research are made as visible and persuasive as possible through good reporting. Three further 'foundation stones' are needed, namely (i) Producing written publications and reports to influence stakeholders, (ii) Producing visual presentations to influence audiences and (iii) Archiving the primary data in accessible formats for further analyses.

These three particular foundation stones are general in nature and are important to all fields of research and not just to research addressing agricultural adaptation to climate change. However, funding agencies may well feel that there are actions that could be taken specifically to help those scientist that they are supporting.

4.3.1. Written reports and publications to influence stakeholders

As with all research, funding agencies would wish to see the results and conclusions of the research that they have supported properly written up and reported in an analytical, persuasive and easily understood format. These reports need to be targeted towards several audiences, ranging from published articles for the wider academic community, advisory manuals for extension agents to policy briefs for decision makers. Each of these requires different types of 'content', format and writing style. Producing these different types of reports is a skill that some people have to a greater extent than others, but fortunately it is a skill that can be taught.

4.3.2. Visual presentations to influence audiences

Increasingly, both within the region and internationally, there are opportunities for scientists involved in climate risk and adaptation research to attend meetings and conferences to give visual presentations of their research. Written work is almost always targeted towards a specific audience who will usually have time available to spend reading the report in detail. Conferences, on the other hand (i) tend to attract audiences with a wider range of specific interests, (ii) allow little time to get the message across, and (iii) usually try to schedule as many presentations as possible.

Under these circumstances, a poorly constructed and poorly delivered presentation will almost certainly fail to have any impact and will become quickly forgotten. The skills required to construct and deliver a compelling presentation are quite different from those required to write good reports; but again, they are skills that can be taught.

If individual institutes do not have access to communication experts who have the skills to help in written and visual presentation, then the training of scientist themselves in these skills might well be a useful activity to be considered for targeted funding support.

4.3.3. Archiving primary data in accessible formats

Funding agencies could play a key role in promoting the archiving of the raw research data that their funds have been used to produce. This applies to all fields of research, but it is particularly appropriate to consider this role in research linked to climate variability and change. This is because these projects often include a demand for the archived primary climatic data from the National Met Services (NMSs) who have themselves devoted considerable resources to the archiving of their historical data. There may sometimes be problems in gaining access to these data, but at least they exist. This is not the case with most raw research data collected by research programmes or by universities. It is time that this changed.

There are both practical and moral issues to be resolved before research scientists will agree to archive their raw data. The key moral issue is that of ownership. Do the data belong to the funding agency, to the individual scientist who was responsible for the data collection, or to the organization that employs the scientist? Failure to resolve these issues limits much current research. Indeed, on occasions scientists even fail to share their data between members of their research team.

The practical issue is how the raw research data should be archived, if there is agreement on the moral issues, in particular on the data ownership.

The reason why it is highly appropriate for funding agencies to be involved in this topic now is twofold:

- Solutions to the practical problem exist. For example, the Dataverse Network at Harvard University [39] is an online digital repository for research data. Although this is initially promoted as being for the social sciences, it also provides a potential solution for all research data collected by different projects. Potential users may either archive their data and supporting documents on the Harvard site, at no cost, or they may choose to download the archiving software (also at no cost) and create their own local "Dataverse".
- Funding agencies are well placed to help recipient organisations to address the moral issues because:
  - They have provided the funds; however
  - They do not want any of these data for themselves, i.e. they keep the moral "high-ground". They merely want to ensure that the data remain available for the benefits of all partners and of future research activities.

In addressing these issues it is vital that the topic of ownership, and hence of archiving, is addressed at the start of any project. Thus, when researchers agree to undertake a project, they also agree to the archiving of their data and of supporting documents.

5. Conclusions

To ensure that African researches are equipped with the best tools and develop strong research capabilities, the authors believe that there is an urgent need to invest in: (i) ways to improve access to information, (ii) ways to enhance the research capacity, and (iii) ways to enhance the impact of the research undertaken.

The following recommendations are the result of extensive work that the authors have undertaken in SSA to support researches to develop adaptation strategies that build resilience of agriculture to climate change. These recommendations are summarised here:

Improved access to information

- Support for a dedicated review of the literature and the production of an easily accessible annotated bibliography of up-to-date climate risk management and adaptation literature.
- Development of 'databases' of previous or on-going projects held by individual institutions and funding agencies.
- Access to high quality and long-term daily weather data is crucial for a critical analysis of climate-induced risk and climate change research. Such data is too important to be considered the property of a single institution and should be viewed as a public good.
- Given the importance of establishing a critical mass of research personnel for the future, support for the development of a comprehensive and integrated curriculum on climate change is essential.

Enhanced research capacity

- Promote rigorous scientific research design and approaches to make sure that research on climate change adaptation is conceived and undertaken in the context of the impacts of other important drivers of change.
- Support for training, both in climate risk analysis and in the use of weather-driven crop growth simulation models, to assess the impact of climate variability and change on agricultural production.
- Individual training should not be funded in isolation, but rather as an agreed capacity development program for institutes to develop the improved working practices of their staff and of their institute in this complex area of climate variability and change.

Enhancing the impacts of research

- Support for good reporting, both written and visual, is essential as it ensures a higher and wider impact of the research outputs and consequently better outcomes and decisions.

- Ensure that primary datasets that, developed using public funds, are properly archived and are made publically available once the researchers have completed their analyses and reporting.

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Acknowledgement

Authors gratefully would like to acknowledge all funding agencies that have supported the work. Thanks are due to the African Development Bank who supported a four year project (2007 – 2010) entitled '*Managing Uncertainty: Innovation Systems for Coping with Climate Variability and Change*' through a grant to the International Crops Research Institute for the Semi-arid Tropics (ICRISAT), and to the Rockefeller Foundation who are currently funding the authors' project entitled '*Supporting the Rockefeller Foundation Climate Change Units (CCU) in East and Central Africa*' (2010-2014).

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