Photo 1: Cattle grazing maize straw in the Ethiopian Highlands. Crops often serve multiple purposes in the agricultural systems of Africa, and maize straw is a key dry-season feed resource for livestock in many places. The impacts of climate change may thus be felt in several different ways in such systems, in addition to its effects on food availability for the farmer's family and cash income for the household. Copyright, Dave Elsworth/ILRI.

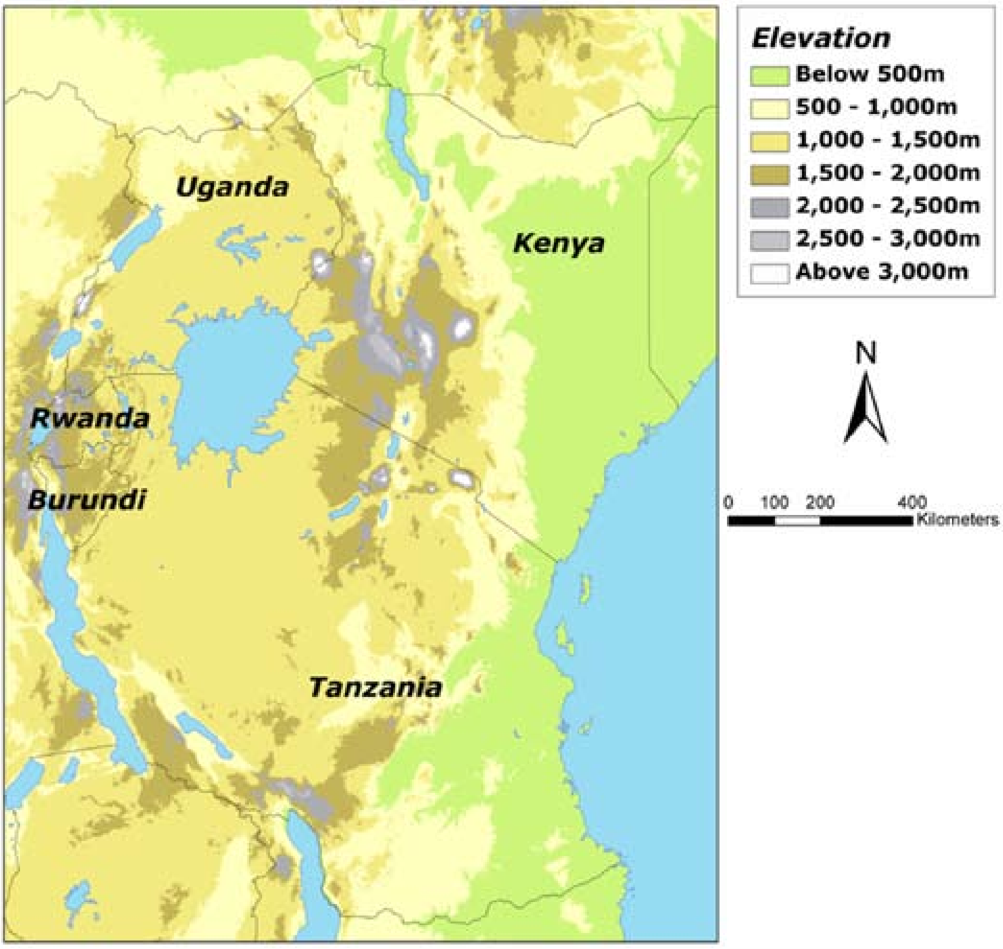
Crop Yield Response to Climate Change in East Africa: Comparing Highlands and Lowlands

Philip Thornton, Peter Jones, Andrew Farrow, Gopal Alagarswamy, Jeffrey Andresen

Climate change will have significant impacts on agriculture, particularly in East Africa where there is such variation in topography and climate. Modelling studies can help to show where these impacts may be largest, to help guide adaptations to ensure food security in the coming decades. Results suggest that crop yield reductions may be expected over 50% to 70% of the area simulated. At the same time, highland areas in parts of the region may see increases in yield potential, which could have a positive impact on householders' incomes and food security in these places.

The impacts of projected climate change during the first half of the current century will pose a serious problem for development in sub-Saharan Africa (SSA), and will add burdens to those who are already poor and vulnerable[1,2]. Many of these impacts will be felt in agriculture, which nevertheless will continue to play a crucial role in SSA through its direct and indirect impacts on poverty, as well as in providing an indispensable platform for wider economic growth that reduces poverty far beyond the rural and agricultural sectors[3].

There is much activity on the part of development agencies and governments to come to grips with these challenges, including the planning and implementation of appropriate adaptation strategies. Development agencies could greatly benefit from information that quantifies the impacts that may arise, so that development assistance can be targeted in appropriate places, depending on the development objectives that are being pursued. There are still knowledge gaps concerning the interacting and multiple stresses on the vulnerability of the poor in Africa, however. One of these is to understand more about how vulnerable households may be affected by increased climatic variability and climate change, to better understand the implications for poverty reduction as well as to be able to assess adaptation initiatives[4,5]. Coping with climate variability is certainly not a new problem for African farmers, but existing coping mechanisms may not be up to the challenges that are likely to be faced in the future[6].



Map 1: The study region, showing elevations. Elevation data source: Reuter, H. I., Nelson, A. and Jarvis, A., 2007. An evaluation of void-filling interpolation methods for SRTM data. International Journal of Geographical Information Science 21 (9), 983 – 1008.

A considerable amount of work has been done already on quantifying some of the agricultural impacts of projected changes in future climate, but most of it to date has been carried out at low spatial resolutions, such as the globe, region, and country[7,8,9]. Particularly for organisations that work with a "pro-poor" mandate in developing countries, in addition to the relatively broad-brush information that such studies provide, there is a need for more detailed information on the impacts of climate change on agricultural systems, so that effective adaptation options can be appropriately targeted.

Linkages between land use and climate change

The work outlined here is part of a larger research project called the Climate–LandInteraction Project (CLIP). This is designed to look at questions of how land-use change affects climate as well as how climate change affects land use. CLIP is quantifying the two-way interactions between land use and regional climate systems at multiple scales in East Africa, a region that is undergoing rapid land-use change. The linkages between land use/land cover and climate change are being examined through the modelling of agricultural systems, land-use driving forces and patterns, the physical properties of land cover, and the regional climate[10].

We have looked at possible impacts on crop yields in the region in some detail, building on previous work[11]. East Africa is very heterogeneous, in terms of topography and altitude. The study region is shown in (MAP 1), covering all of Kenya, Uganda, Tanzania, Rwanda and Burundi, and parts of Ethiopia, Congo, Malawi and Mozambique. Nearly 70% of this region is highland or mountains, lying at altitudes above 1000 m.

We ran two crop models, one for main-season maize[12] and one for secondary-season Phaseolus beans[13], with daily weather data that are characteristic of future climatic conditions in the region, as represented by a combination of two climate models and two contrasting greenhouse-gas emission scenarios. These crop models use a daily time step, and calculates crop phasic and morphological development using temperature, day length and genetic characteristics[14].

Development and growth processes are influenced by water and nitrogen balance submodels[15]. For the maize crop, we ran simulations using a short-season Kenyan variety as a proxy for a well-adapted generic maize variety, using typical current smallholder cultural practices such as little or no fertilizer and low planting densities. Bimodal rainfall patterns are common in the study region, and there are quite large areas where two growing seasons occur per year. For these areas, we simulated bean production also, by planting beans after the maize crop had been harvested. As for the maize runs, simulated cultural practices reflect regional management. Details of all the methods used are described elsewhere[11,16].

We first ran replicated (multiple-year) "baseline" simulations and produced maps that show average simulated maize yields when grown in the primary season under current climatic conditions, and average simulated bean yields in the secondary season, where this is feasible. We than ran the crop models again, but using daily data characteristic of possible future climatologies in 2050. We ran these simulations only for those areas of the study region where maize and secondary-season beans could potentially be grown, on the basis of soil and climatic suitability. Most of these areas lie at higher elevations. In comparing current and future production, we found that if all such areas were indeed cropped, then "regional production" would decline by 1-3% for the lower emission scenario, and by 11-15% for the higher-emission scenario used, depending on the climate model used.

There are many places in the study region where we found a statistically-significant increase or decrease in mean simulated yield compared with the baseline yield, for primary-season maize and secondary-season beans to 2050, using one of the climate models and the higher emission scenario. Maize yields are projected to be reduced (often by 20% or more) for large areas in the north-west of the study region (northern Uganda, southern Sudan) and for the more semi-arid areas of Kenya and Tanzania where maize cropping is possible. In contrast, maize yields are projected to increase in some of the highland areas of the region: in the southern Ethiopian highlands, the central and western highlands of Kenya, and the Great Lakes Region. Projected yield losses in secondary-season beans are rather more widespread, with many parts experiencing yield losses (sometimes of up to 350 kg per ha and more). Other areas, such as the western highlands of Kenya, the Great Lakes region, and northern Mozambique, are projected to see substantial increases in bean yields.

The results show that crop yield responses to the changing rainfall amounts and patterns and the generally increasing temperatures projected by climate models vary by crop type and by location. For the range of climate model-scenario combinations that we considered, the modest aggregate production decreases that are projected to 2050 hide a large amount of variability, and under the higher-emission scenario, substantial maize and bean yield reductions may be expected over 50% to 70% of the area simulated. At the same time, the highland areas in many parts of the region may see increases in yield potential, which could have a positive impact on householders' incomes and food security in these areas. We should point out that there are likely to be changes in the type, distribution and severity of crop diseases as a result of the changing climate. These are not taken into account in these model runs, but they may well affect the yields that can be obtained under relatively low-input conditions.

Temperature and yield response

We have done other analysis that shows that a substantial part of this heterogeneity in yield response can be explained by temperature effects. In maize, at high altitudes, yields may increase as temperatures increase, but at most lower elevations, yield changes also depend on water availability, and many places will see increasing water stress in the maize crop, all other things being equal. For secondary-season beans, temperature-driven yield increases will occur at higher elevations or up to average temperatures of about 20-22 °C. Beyond these temperatures, yields will tend to decline. These results suggest that there may be a future need for various adaptation options: more drought-tolerant maize varieties, for example, coupled with management practices that can make the most of available rainfall such as water harvesting. For bean production, a shift in bean cropping to higher elevations may be appropriate in some situations.

These results should be interpreted with caution, as there are various sources of uncertainty associated with them. There are issues associated with downscaling the outputs of climate models, and results depend to some extent on the climate model used (they are all simplifications of highly complex processes) and on the emission scenario used (the future pathway of global development cannot be known with any certainty). Also, the yield simulations are subject to errors of data input and model specification. Nevertheless, this kind of analysis is useful as a first step in identifying possible "hotspots" in East Africa where cropping adaptations may need to be implemented. The results also highlight the need to assess impacts at the household level. Yield responses of maize and beans to climate change are different, but many smallholder systems in the region include a range of additional or different crop and livestock enterprises. Maize stover is a key dry-season feed resource for cattle in many places, for example, and any reductions in maize biomass for livestock may need to be made up in other ways. There are some locations in the study region where maize yield reductions may be able to be offset by increases in bean yields, but there are other places where both suffer yield reductions. In general, we do not know what the effects may be of these impacts and their interactions with other farm and non-farm livelihood strategies on household income and food security. Further work needs to be done to assess the likely system-level impacts of climate change in the region, to see where trade-offs are possible, where new opportunities present themselves, and where action is needed if adaptation is to be effective.

AUTHORS

Dr Philip K Thornton, *Senior Scientist and consultant*, International Livestock Research Institute (ILRI), PO Box 30709, Nairobi 00100, Kenya (p.thornton@cgiar.org)

Dr Peter G Jones, Waen Associates, Y Waen, Islaw'r Dref, Dolgellau, Gwynedd LL40 1TS, Wales, UK (p.jones@cgiar.org)

Andrew Farrow, Spatial Analyst, CIAT-Africa, Kawanda Agricultural Research Institute, Kampala, Uganda (a.farrow@cgiar.org)

Dr Gopal Alagarswamy, *Research Associate*, Department of Geography, Manly Miles Building, Michigan State University, East Lansing, MI 48824, USA (alagarsw@msu.edu)

Dr Jeffrey A Andresen, *Associate Professor and State Climatologist*, Department of Geography, Michigan State University, East Lansing, MI 48840, USA (andresen@msu.edu)

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Philip K Thornton and Andrew Farrow are members of MRI's Global Change Research Network in African Mountain

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