Climate change risks for African agriculture

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The Intergovernmental Panel on Climate Change (IPCC) assessment of major risks for African agriculture and food security caused by climate change during coming decades is confirmed by a review of more recent climate change impact assessments (14 quantitative, six qualitative). Projected impacts relative to current production levels range from −100% to +168% in econometric, from −84% to +62% in process-based, and from −57% to +30% in statistical assessments. Despite large uncertainty, there are several robust conclusions from published literature for policy makers and research agendas: agriculture everywhere in Africa runs some risk to be negatively affected by climate change; existing cropping systems and infrastructure will have to change to meet future demand. With respect to growing population and the threat of negative climate change impacts, science will now have to show if and how agricultural production in Africa can be significantly improved.

Climate change is projected to compromise agricultural production, especially in smallholder systems with little adaptive capacity, as currently prevalent in many parts of Africa. In its Fourth Assessment Report (AR4) of 2007, the Intergovernmental Panel on Climate Change (IPCC) evaluated the scientific literature available up to the Working Group II literature cutoff deadline on April 21, 2006. Focusing on Africa in 2020, a key conclusion in the IPCC Synthesis Report (SYR) and the Summary for Policy Makers of the Working Group II Report was that, "[b]y 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition" (1). This conclusion, or at least its first sentence, has been debated in the media, with criticisms being raised on the nature of the underlying science (e.g., peer-reviewed or other literature) and on procedural issues (e.g., whether the knowledge contained in the underlying scientific literature was properly represented on all levels of the report). Scrutiny of all statements concerning African agriculture through the interconnected IPCC AR4 reports demonstrates that the assessment is consistent among the components of the report and supported by published literature. However, the first sentence of this quite general conclusion is based on one single reference (2) that does not allow for a scientific evaluation of its findings (3) (*SI Appendix*) and refers to only dry years rather than to average annual yields (3).

Although this is a procedural flaw that might have been avoided through the improved IPCC assessment rules (as, e.g., suggested by the InterAcademy Council [4]), it is essential to avoid misinterpretations. In fact, the questionable sentence itself is guarded with sufficient qualifying terms (e.g., "some," "could," "up to") that it does not draw a strong conclusion anyway. It is, however, because of its short-term perspective ("by 2020") and its severity (i.e., 50% reduction), a vivid example that illustrated the accompanying SYR statement that "[a]gricultural production … in many African countries is projected to be severely compromised" (1). Here, we do not focus on this single illustrative but debatable example, but on the broader conclusion about African yield risks. For that purpose, we review newer studies on climate change and African agriculture to see whether the overall IPCC assessment is still supported by recent scientific findings and if it can be made more informative. Similar to the IPCC, here we also include non–peer-reviewed literature that sufficiently describes its methodology and allows for an evaluation of its findings.

Since approval and publication of the AR4, new literature has emerged concerning risks for African agriculture and food production that are caused by anthropogenic climate change. These studies use statistical, econometric, or process-based models for different time frames and different basic assumptions, assessing impacts at specific locations, in regions or for the entire continent, for single crops, production systems, or the entire agricultural sector. Most studies indicate the potential for positive as well as negative impacts: for some crops, the published projected climate change impacts therefore range from impossibility of "normal agricultural activity" (5, 6) to strong increases in agricultural yields (7, 8). Typically, impact assessments are given for specific time horizons, and impacts vary considerably by region and/or crop. Fig. 1 (5, 7–19) shows the range of reported impacts on African agriculture per spatial domain (pixel to continent), illustrating the vast range of possible impacts. In most cases, these include severe negative impacts and often also yield substantial potentials for improvement. Although the 2020 time slice is hardly assessed by the new literature, any indication of risk in this near future must be of particular concern because of the lack of time for implementation of any adaptation measures. In the more distant future (e.g., toward the end of the 21st century), adaptation may substantially reduce the potential impacts (9). Adaptive capacity may be strengthened by advances in agricultural development, as African agriculture in many places currently operates at very ineffective levels (ref. 20; also see http://www.fertilizer.org/ifa/ifadata/search) or by using very low levels of inputs (21). Even though African farmers already use a broad variety of mechanisms to cope with variable weather conditions and adapt to climate change (e.g., ref. 22), improved strategies for increasing resilience and coping with risks are still needed in many parts of Africa (23, 24).

Most studies reviewed here analyze climate-change impacts on African agriculture in isolation, i.e., they disregard changes in the global demand and supply patterns that will affect the production and profitability of agricultural systems worldwide, as shown, for example, by Lotze-Campen et al. in 2010 (25) for changes in supply patterns under different trade scenarios. A notable exception is the study by Nelson et al. in 2009 (8). So far, little is known about changes in the agricultural value chain other than those in biophysical productivity. This also holds true for the econometric studies, which cannot account for changes in market or production systems (*SI Appendix*).

The range of projected impacts is very broad because of the range of underlying assumptions, such as greenhouse gas emission trajectories, climate model parameterizations, biophysical impact estimates, management practices, and socioeconomic conditions in the future. Most studies present only an arbitrary selection of

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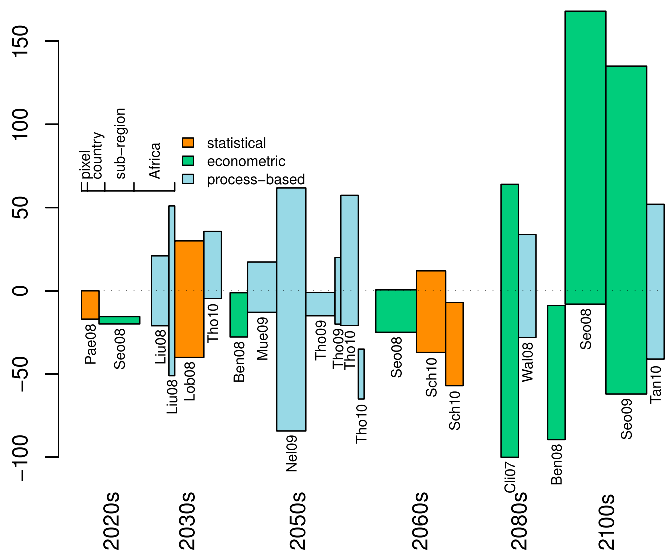

Fig. 1. Projected ranges of climate change impacts on African agriculture, expressed as change in percent relative to present conditions. Bar widths indicate the spatial extent of the projection, and shading depicts the methodology. Sources: Pae08 (10), Seo08 (9), Liu08 (7), Lob08 (11), Ben08 (12), Mue09 (13), Nel09 (8), Tho09 (14), Tho10 (15), Sch10 (16), Cli07 (5), Wal08 (17), Seo09 (18), and Tan10 (19).

available climate projections, despite the considerable spread between them, especially with respect to precipitation patterns, which may even yield different signs of the effect (26). Guidance for policy can best be drawn from a risk management perspective, studying specifically the probability of high-impact scenarios. Rainfall patterns are the dominant climatic factor for agricultural production in Africa, although a new review of historical events has shown that sensitivity to higher temperatures could also be considerable (27). Of all major world regions, Africa is projected to rank highest in drought-caused yield reductions (28). Increasing temperatures exacerbate the effects of water and rainfall reductions and can partially remove any advantage that occurs as a result of increased precipitation (14).

Overall, the more recent literature shows that the conclusion of the AR4 SYR, that "[a]gricultural production … in many African countries is projected to be severely compromised" (1), remains valid, also in its confidence rating (i.e., high confidence).

Although there is still no comprehensive continent-wide assessment for all major cropping systems in Africa, the new results show more clearly how the current production systems might be impacted in regionally differing ways: some regions are at risk for severe reduction or even total loss of agricultural production (6), whereas others could benefit from improved production conditions as a result of projected increases in precipitation. Some crops (e.g., wheat) are more susceptible to warming than others (e.g., millet), which is also reflected in model projections (7, 8). Climate impacts will vary by farm types, likely causing economic damage to farmers and national gross domestic product (9, 12, 18). Future agricultural and development policies will have to consider these risks to current production systems, the livelihood of African farmers, and the associated market and infrastructure (29).

Besides direct climate change impacts, it is also likely that climate change will exacerbate additional risks (30). Most of the quantitative assessments are monodisciplinary and therefore disregard any mechanisms that affect agricultural productivity other than direct climate change effects. There are some qualitative studies that discuss the potentially severe impacts of indirect climate change effects such as cropland inundation, erosion, and salinization caused by sea level rise (31), altered crop resistance to insect damage (32), and the response of pests and pathogens to climate change (33).

Against this background, the quantitative results presented in recent studies must be considered rather optimistic. The strength of CO_2 "fertilization" has a large effect on projected impacts (8), and is possibly the only process that could actually buffer against some of the more detrimental impacts of climate change. There is also some uncertainty embedded in the different methods used to project climate change impacts on African agriculture. Econometric models derive statistical relationships among farmers' incomes, production systems, and environmental conditions, which is strongly limited by available reference data and the assumption that statistical relationships can be extrapolated over a period of several decades into the future (18). Statistical models of agricultural productivity often have little explanatory power (11) and generally are, like econometric approaches, unsuitable for extrapolation to novel conditions such as climate change. Process-based models are often limited by the lack of site-specific parameterization of management options and varieties (8, 13) and the risk of overtuning (34). A more detailed discussion of sources of uncertainty in projections of climate change impacts on African agriculture is presented in the *SI Appendix* and in ref. 34.

Climate change represents a significant threat to current African production systems, infrastructures, and markets, and therefore farmers' livelihoods. Undoubtedly, agriculture will have to change dramatically to meet future demands. This will be irrespective of climate change, given the largest population growth rates worldwide as well as the shifting patterns of food intake in the course of urbanization and development. Africa has huge potentials to increase its agricultural productivity, with yield gaps of 10% (Egypt) to 90% (Angola) (20). Much of these inefficiencies in African agriculture can be explained by limited market access (20), affecting inter alia availability of fertilizers and pest control (21, 35). In economic terms, the risk of severe climate change impacts on agricultural production systems in Africa is therefore likely to affect a food production system that already struggles to meet the challenges of a changing global society (36).

Climate change impacts on African agriculture are of major concern not only to African farmers, but also to national governments, regional decision makers, and international organizations: variability of crop yields has long been a major cause of migration in Africa (37). In one study, global warming is projected to increase the likelihood of civil wars in Africa (38), partly because of the potentially devastating effects on crop yields, although this view has been disputed (39, 40). Being already burdened with poverty, food insecurity, and low adaptive capacity, African societies are most vulnerable to climate change. Although vulnerability to climate change is very unevenly distributed across Africa (41), the potentially damaging climate effects and risks pose serious threats to sustainable development in many parts of Africa (42). The crucial role of climate change—with its beneficial as well as damaging potential—are beginning to be reflected in development cooperation programs and will need to continue to be (43).

The overall picture may seem diffuse and unsuited for clear conclusions: following the IPCC confidence rating guideline (44), there is very high confidence that climate change will negatively affect at least parts of African agriculture (14 of 14 studies), while simultaneously, there is also high confidence that African agriculture will be partly affected positively by climate change (12 of 14). As there are so many climatic and nonclimatic aspects that determine agricultural productivity that are mainly not considered in these studies, there is only low confidence in what the overall impact of climate change on African agriculture will be. Despite all uncertainty in climate change and impact projections and incomplete coverage, there are already robust conclusions for policy makers and research agendas. There is broad consensus among the studies that all African agriculture runs some risk to be negatively affected by climate change, i.e., no one is on the safe side. Existing cropping systems will have to change, and scientists need to provide more information on what the suitable adaptation options are.

Assessing potential impacts has helped to make the AR4 finding indisputable that "[a]gricultural production … in many African countries is projected to be severely compromised," but now this needs to be accompanied by an evaluation of adaptation measures as well as strategies for increasing resilience and coping with risks (23). There are also first indications on which adaptation measures are more promising than others: changes in crop mixes (7, 8) need to be accompanied by increased international trade (45), which needs to be facilitated by better infrastructure, particularly roads (8). How African societies can generate the income to increase imports as proposed by Parry et al. in 2005 (45) and others remains yet to be answered. International engagement in African agricultural production systems, in which foreign countries or companies claim parts of Africa's productive cropland, may yield some development and income opportunities but also constitutes risks to food security (46) and needs to be critically evaluated by policy makers. Science will have to show if and how "[a]gricultural production … in many African countries" can be significantly improved (47).

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