Climate change impacts on African crop production

Working Paper No. 119

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Abstract

According to the most recent IPCC report, changes in climates over the last 30 years have already reduced global agricultural production in the range 1-5 % per decade globally, with particularly negative effects for tropical cereal crops such as maize and rice (Porter *et al.*, 2014). In addition, there is now mounting evidence suggesting that even at low (+2 ºC) levels of warming, agricultural productivity is likely to decline across the globe, but particularly across tropical areas (Challinor *et al.*, 2014). This Working Paper provides an overview of projected climate change impacts on crop production and suitability across Africa, using a combination of literature review, models and new data analysis

Keywords

Climate impacts, Africa, Crops, Agriculture Production, Climate Change

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Contents

Introduction

According to the most recent IPCC report, changes in climates over the last 30 years have already reduced global agricultural production in the range 1-5 % per decade globally, with particularly negative effects for tropical cereal crops such as maize and rice (Porter *et al.*, 2014). In addition, there is now mounting evidence suggesting that even at low (+2 ºC) levels of warming, agricultural productivity is likely to decline across the globe, but particularly across tropical areas (Challinor *et al.*, 2014). Significantly greater are projected at higher levels of warming (i.e. where no mitigation policies are enforced) as critical crop physiological thresholds related to reproductive capacity and/or acceleration of senescence are exceeded (Gourdji *et al.*, 2013; Teixeira *et al.*, 2013).

This Working Paper provides an overview of projected climate change impacts on crop production and suitability across Africa, using a combination of literature review, models and new data analysis. The paper focuses on the biophysical impacts of nine agronomic crops critical for food security: maize, common bean, cassava, sorghum, yam, finger millet, pearl millet, groundnut, and banana, as well as on one cash crop: coffee, and provides insights as to the countries and crops in Africa that are projected to be most negatively impacted. The Working Paper also reviews some potential avenues for adaptation. All analyses focus on rainfed agriculture.

Paper's key messages:

- Geographically, the majority (~90 %) of currently cropped maize area is projected to experience negative impacts, with production reductions in the range 12-40 %.
- Common bean yield is highly sensitive to climate: small changes in yield within ±5 % of current yield levels can be expected in less than 2% of the agricultural area of the continent.
- Sorghum, cassava, yam, and pearl millet show either little area loss or even gains in suitable area, whereas common bean, maize, banana and finger millet are projected to reduce their suitable areas significantly (30-50 %).
- Suitability projections also suggest that opportunities may arise from expanding cropping areas in certain countries and regions (e.g. cassava towards more temperate regions in Southern Africa, or yam outside West Africa).
- Climate change will reduce area suitable for coffee, on average across emission scenarios, by about 50 %, with arabica coffee being most negatively impacted. Two phenomena will likely be observed for coffee in East Africa: (1) an overall reduction in arabica growing areas accompanied by migration and hence concentration towards higher altitudes, and (2) a replacement of heat-stressed arabica areas (< 1,500 m.a.s.l.) by the more heat-tolerant robusta.

Summary of Impacts

For tropical areas, model-based estimates indicate that if no adaptation actions are taken, on average, maize productivity could decrease by 5-10%, whereas rice productivity could decrease by 2-5 % by every degree of warming during the 21st century (Fig. 1). Adaptation can counter some of these negative impacts, but it is critical that measures are implemented early, as impacts are already taking place in a number of cases or are likely to be observed in the next 10-20 years.

For Africa, previous work on climate change impacts indicates that maize (-5 %), sorghum (-14.5 %) and millet (-9.6 %) yields are set to decline significantly, whereas rice and cassava yields are projected to not be significantly impacted during the 21st century (Knox *et al.*, 2012). Maize, in particular, contributes the greatest calories (mean contribution of 16 %, range: 0-60 %) and is grown across the greatest area. During the 21st century, total maize output is projected to decrease at a rate of 3-5 tonnnes per decade from historical levels as a result of climate change (Fig. 2). According to these projections, if no adaptation occurs, by the end of the 21st century, in the best scenario, total maize production in Africa would have decreased from ~42 to ~37 million ton per year (12%), whereas in the worst-case scenario maize production could be as low as 25 million ton per year (40% reduction) (Fig. 2A).

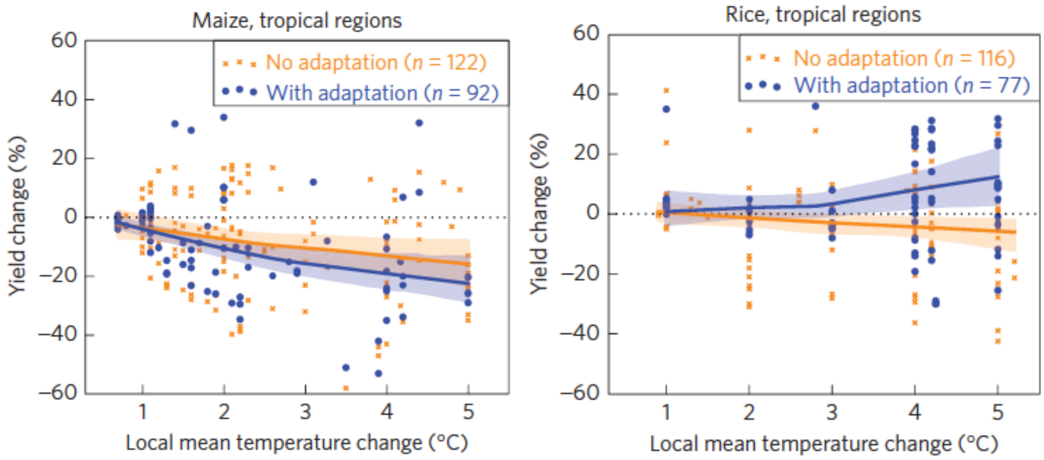


Figure 1: *Percentage yield change as a function of temperature for rice and maize across tropical regions. Taken from Challinor et al. (2014).'*

Geographically, the majority (~90 %) of currently cropped maize area is projected to experience negative impacts. Humid and West African countries (including those across the Sahel) are amongst the most negatively impacted, with mean production losses between 20 and 40 % by 2050s [RCP8.5] –equivalent to +2 ºC above pre-industrial temperatures (see Fig. 2B). Crop yield losses in these areas are mostly mediated through shortened cropping seasons and heat stress during the crop's reproductive period (Thornton *et al.*, 2009; Cairns *et al.*, 2012). These projections are robust, thus suggesting that adaptation of maize production should be a priority for many African countries, but particularly for those in the Sahel.

Areas unlikely to exhibit neither significant positive or negative impacts from climate change on maize production occur mostly in Southern Africa (Namibia and Botswana, Zimbabwe, Lesotho and northern South Africa) and some areas of Eastern Africa (eastern Kenya). In southeastern Namibia and Lesotho, in particular, crop production is expected to increase significantly (>50 %), whereas in Zimbabwe, northern South Africa, and eastern Kenya production tends to change much less, often with changes within ±5 % (Fig. 2B). As climate change intensifies, however, areas with production gains or stable production tend to reduce their size and/or may disappear completely.

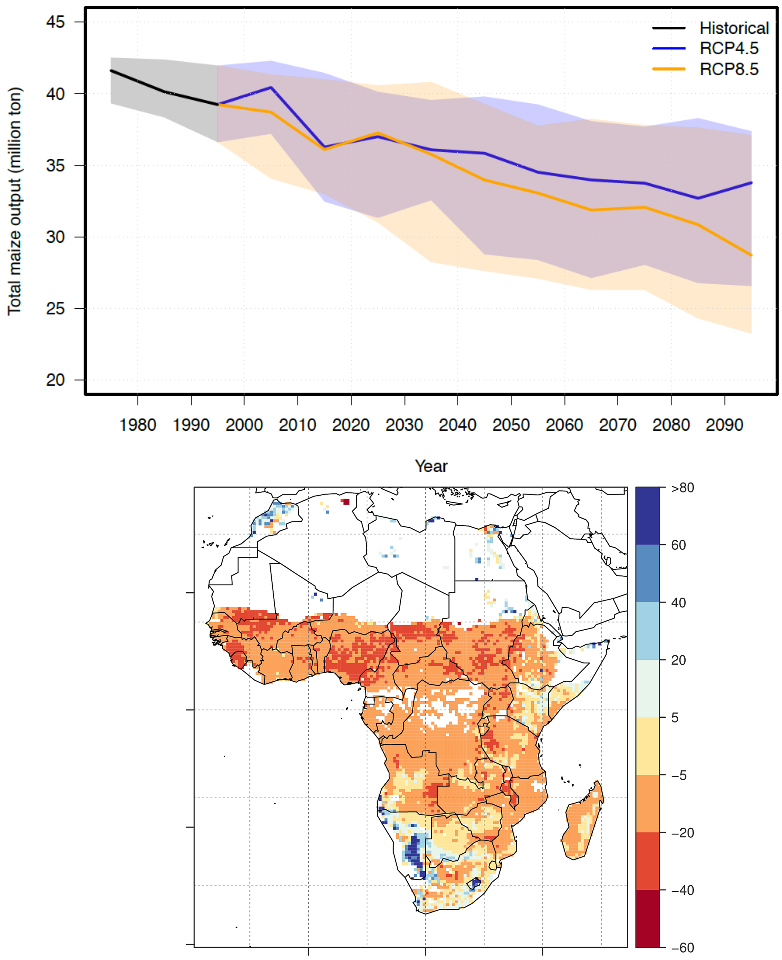


Figure 2: *Projected changes in maize production. (A) Future projected African maize total production during the 21st century and two future emissions pathways: intermediate (RCP4.5) and high-end (RCP8.5); and (B) spatial distribution of percentage change in production by 2050s and RCP8.5 (high-end emissions) in relation to the mean production of 1971-2000. This figure was constructed using the outputs of the Agricultural Model Intercomparison and Improvement Project (AgMIP) [see Rosenzweig et al. (2014), freely available at http://esg.pik-potsdam.de/esgf-web-fe/].*

Common bean (*Phaselous vulgaris* L.) is of considerable importance to the nutrition and food security of many people in Africa. Substantial yield losses for bean in most of sub-Saharan Africa have been projected for a range of different scenarios for the current century (Lobell *et al.*, 2008; Thornton *et al.*, 2009, 2011). Results of some new bean model simulations are shown in Fig. 3. Continent-wide production decreases (relative to mean production for the period 1971-2000) are shown in Fig. 3A for RCP4.5 and RCP8.5 for two time periods centered on 2050 and 2080.

These results may be compared directly with those of maize presented above [based on Rosenzweig et al., (2014)], in that the same soils data and daily weather data from five climate models were used, although only one crop model was used. Fig. 3B shows the distribution of percentage changes in production by the 2050s for RCP8.5. Production and yield decreases of 40% and more are projected over large areas of the Sahel, east and Central Africa and southern Africa. Some yield increases are projected in parts of the East African highlands, western regions of southern Africa, and some of the coastal areas of North Africa. The results highlight that bean yield is highly sensitive to climate: small changes in yield within ±5% of current yield levels can be expected in less than 2% of the agricultural area of the continent. Much larger yield changes can be expected, in general.

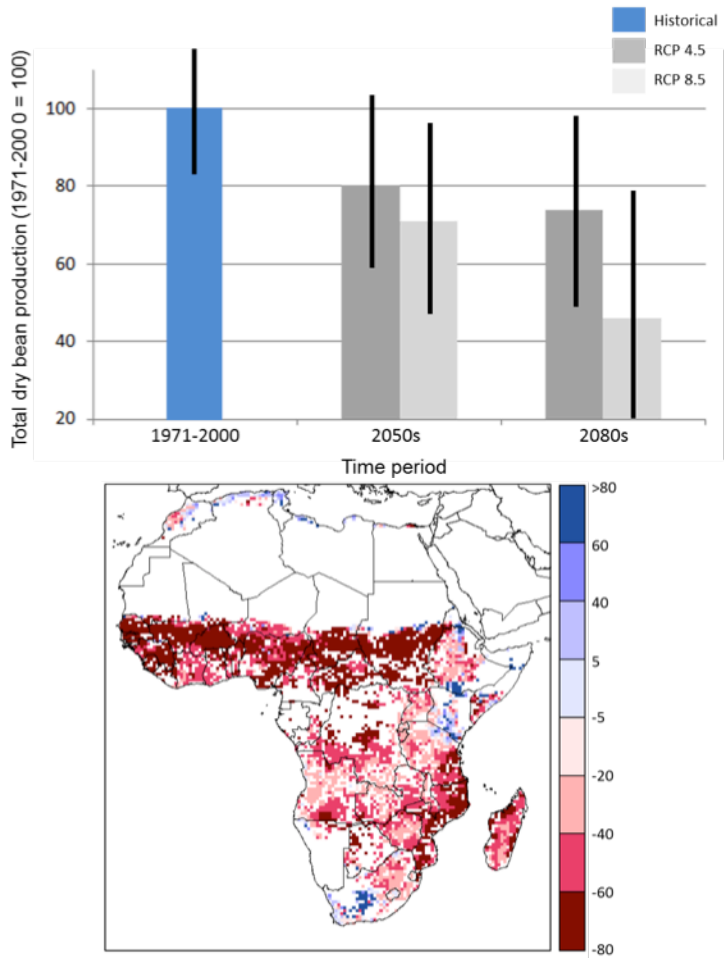


Figure 3: *Projected changes in dry bean production. (A) Future projected African bean production during the 21st century and two future emissions pathways: intermediate (RCP4.5) and high-end (RCP8.5), relative to 1971-2000; and (B) spatial distribution of percentage change in production by 2050s and RCP8.5 (high-end emissions) in relation to the mean production of 1971-2000. These results were generated using weather data from the Agricultural Model Intercomparison and Improvement Project (AgMIP) (Rosenzweig et al., 2014), soils data from the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012) clustered using methods in Jones and Thornton (2015), and the DSSAT cropping system model (Jones et al., 2003).*

As stated above, for the entire set of crops suitability simulations were produced with the EcoCrop model. Relative to historical (1971-2000) climate, these simulations indicate that impacts vary substantially by crop and region, with sorghum, cassava, yam, and pearl millet showing, on average, either little area loss or even gains in area in most regions (Fig. 4). Conversely, common bean, maize, banana and finger millet are projected to reduce their suitable areas significantly (30-50 %) in many regions. Maize, in particular, shows large decreases in suitable area across the Sahel (in agreement with previously described production projections, see Fig. 2), particularly in Senegal, Mali, Burkina Faso, and Niger, and to some extent also in humid West Africa (Nigeria, Togo, Benin and Ghana, also see Fig. 5). Suitable area reductions for maize are less severe elsewhere, though Kenya, Mozambique and Botswana show some reduction in area. Most of these reductions result from temperatures that exceed the optimal and marginal maximum temperatures at which the crops can grow, and in a few cases (e.g. pearl millet, sorghum and yam) decreases in precipitation.

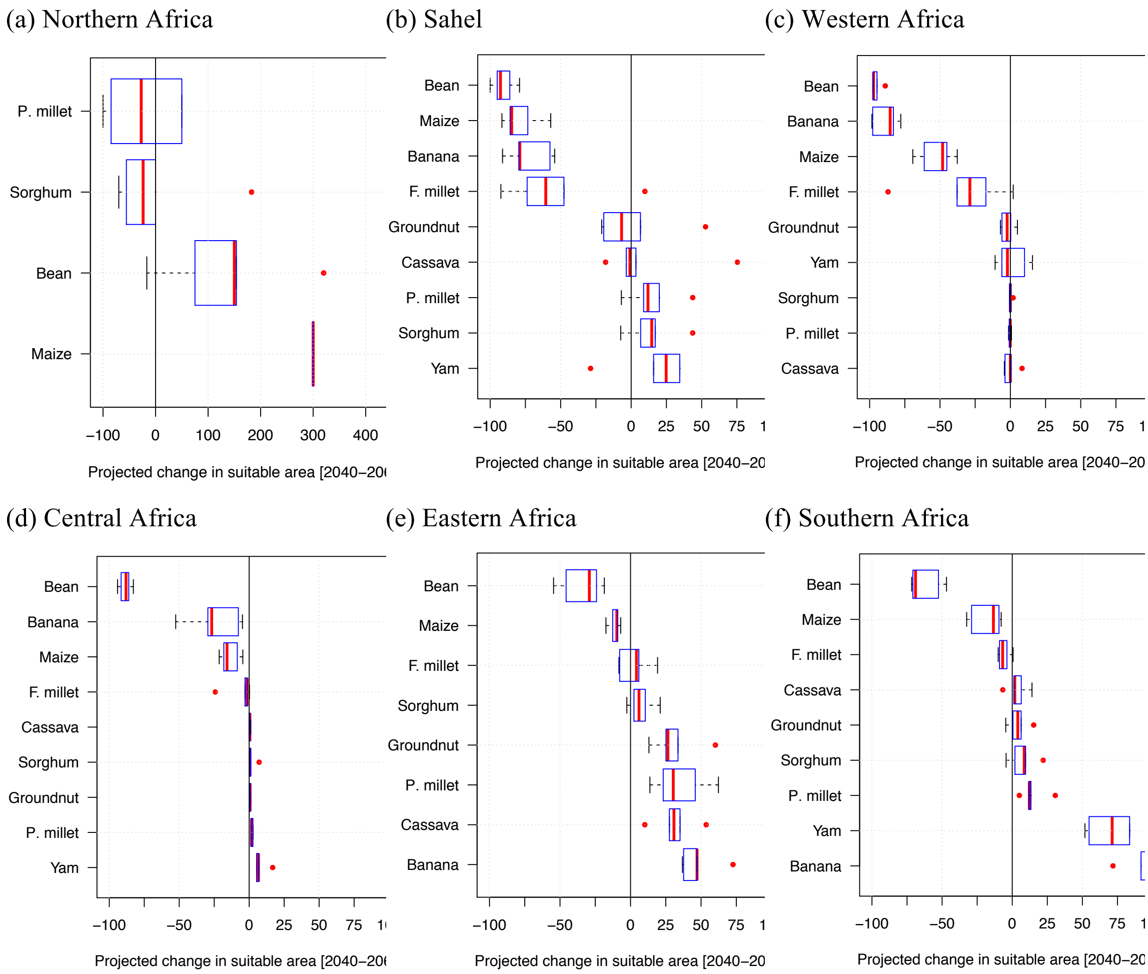
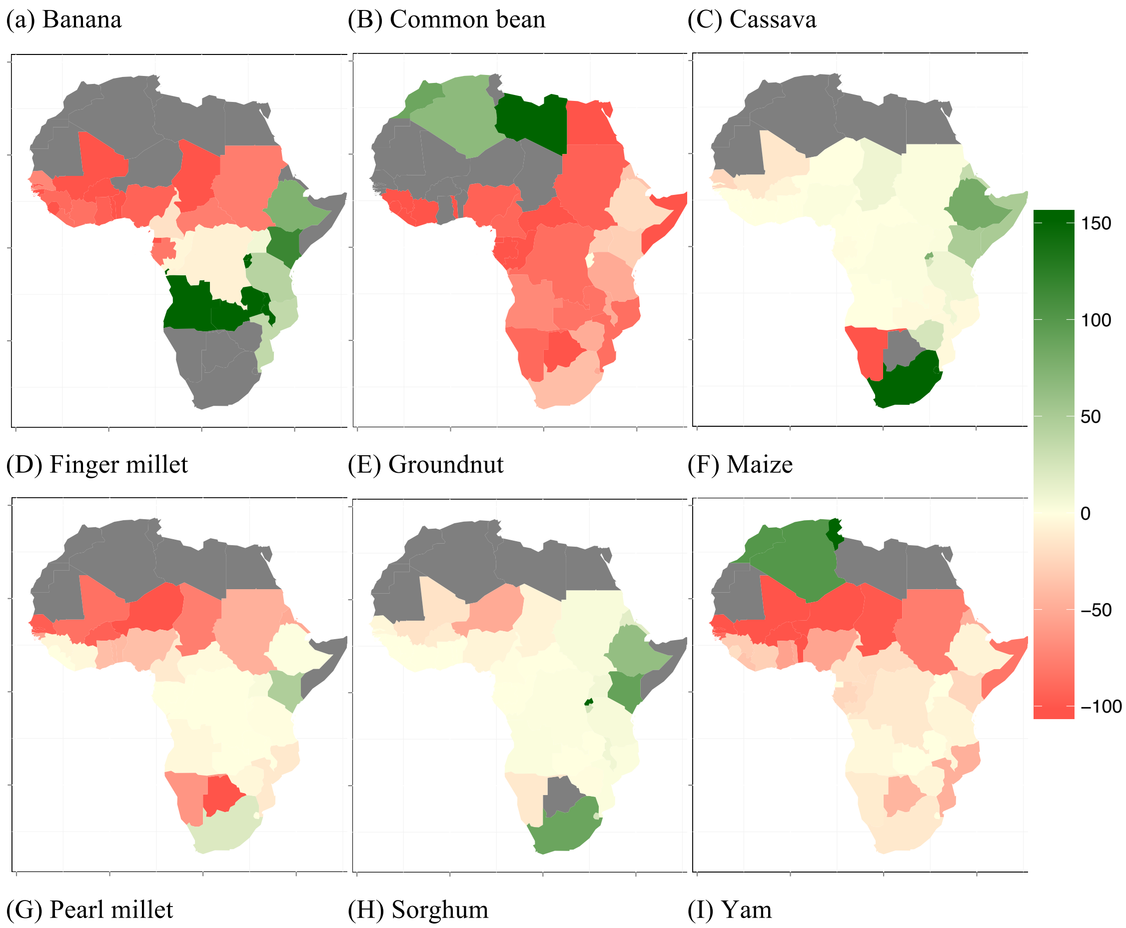


Figure 4: *Projected climate change impacts by 2050s (RCP8.5) and associated uncertainties for six different regions of Africa. Countries are associated only to one region following Lobell et al. (2008) as follows: Northern Africa: Mauritania, Morocco, Algeria, Tunisia, Libya, Egypt, and Eritrea; Sahel: Mali, Burkina Faso, Niger, Chad, Sudan and South Sudan; West Africa: Senegal, Ivory Coast, Guinea, Guinea-Bissau, Gambia, Liberia, Nigeria, Benin, Togo, Ghana and Sierra Leone; Central Africa: Cameroon, Central African Republic, Congo, Democratic Republic of the Congo, Equatorial Guinea and Gabon; East Africa: Tanzania, Uganda, Kenya, Ethiopia, Eritrea, Somalia, Rwanda, and Burundi; and Southern Africa: Zimbabwe, South Africa, Botswana, Lesotho, Swaziland, Mozambique, Zambia, Malawi, Angola and Namibia. Variation for each region is a result of using 5 GCMs for the EcoCrop simulations.*



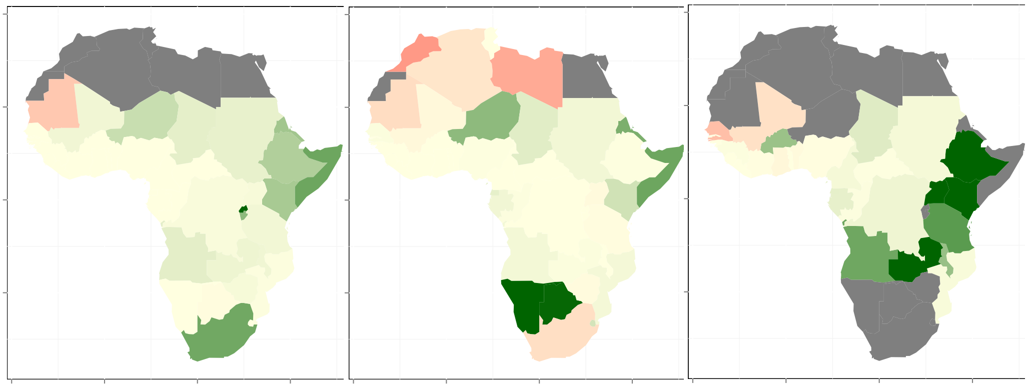
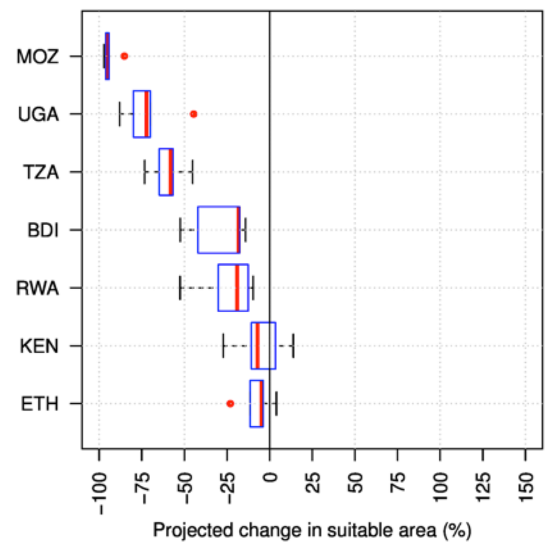


Figure 5: *Projected median changes in percentage area suitable for 9 key crops for 2050s for RCP8.5 (high-end emissions). Changes in area suitable are calculated as the percentage of area suitable in the future relative to the area suitable in the historical period. Note that this scenario and time period (2050s, RCP8.5) is equivalent to a global mean temperature of +2 ºC above preindustrial levels.*

Suitability projections, however, also suggest that opportunities may arise from expanding cropping areas in certain countries and regions. A clear example of this situation is cassava, for which there could be opportunities beyond the geographical limits where it is currently cultivated, particularly towards higher elevation areas in East Africa, and towards more temperate regions in Southern Africa. A similar situation can be seen for yams in East Africa, where projections indicate large increases in cropping area. Additionally, in East Africa, there could be further opportunities for bananas, groundnuts and millets (Fig. 4). The studies of Zabel et al. (2014) and Lane and Jarvis (2007) also support the finding that geographic shifts in suitable areas for crops are likely under climate change. For Africa, this means that complex systemic and transformational changes in farming systems accompanied by a combination of improved trade policies and shifts in diets will be needed in order to capitalize on geographic shifts in suitable areas.

At the country level, Sahelian countries are projected to be the most negatively impacted. In particular, Mali, Senegal, Burkina Faso and Niger, are projected to decrease their suitable areas for 70 % or more than of the crops (Fig. 5). In these countries, currently, agricultural yields are low and agriculturally suitable areas are limited (Licker *et al.*, 2010; Zabel *et al.*, 2014), which implies that unless appropriate adaptation strategies (e.g. livelihood diversification through agroforestry, breeding climate-smart varieties, improved crop management through site-specific or precision agriculture) are developed, many of the crops analyzed here can no longer be grown in these countries (or at least in a substantial part of them).

Information is in general more sparse for other cash crops than coffee (i.e. cocoa, tea); hence, this report summarizes impacts estimates for coffee alone, based on the niche-based model simulations of Bunn et al. (2014), for the main coffee production countries of Africa for both arabica (*C. arabica*) and robusta (*C. canephora*) coffee. Models indicate that impacts are highly negative for arabica coffee, with arabica-suitable areas of Mozambique, Uganda and Tanzania almost disappearing (> 50 %, Fig. 6), areas of Burundi and Rwanda reducing significantly (20-50 % reduction), and the least significant (but still noticeable) negative effects on Kenya and Ethiopia (< 15 % reduction). For robusta coffee, models indicate that three countries might experience substantially negative impacts: Mozambique, Uganda and Tanzania, whereas the rest of countries (Ethiopia, Kenya, Rwanda and Burundi) are more likely to experience gains in robusta-suitable areas. On the basis of these results, it is likely that two phenomena will be observed for coffee in East Africa: (1) an overall reduction in arabica growing areas accompanied by migration and hence concentration towards higher altitudes; and (2) a replacement of heat-stressed arabica areas (< 1,500 m.a.s.l.) by the more heat-tolerant robusta (Bunn *et al.*, 2014).



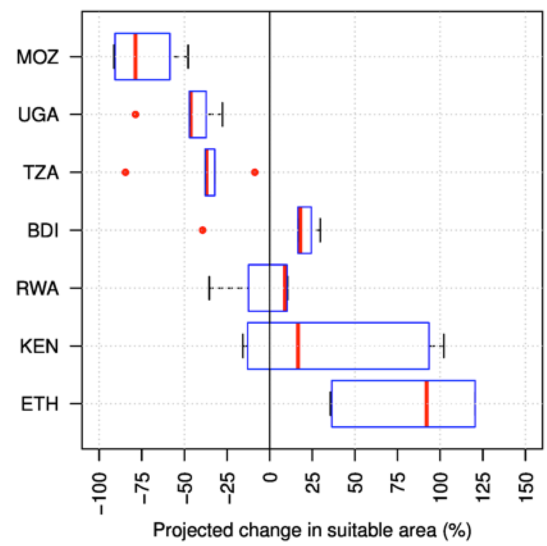


Figure 6: *Projected changes in percentage area suitable for arabica (left) and robusta (right) coffee for 2050s for RCP8.5 (high-end emissions). Changes in area suitable are calculated as the percentage of area suitable in the future relative to the area suitable in the historical period. Note that this scenario and time period (2050s, RCP8.5) is roughly equivalent to a global mean temperature of ca. +2 ºC above preindustrial levels.*

All model-based estimates, such as the ones presented here, are subject to uncertainty. Whilst Fig. 4-6 show the median of 5 GCMs for one concentration pathway (RCP8.5) and one period (2050s), Fig. 4 and Fig. 6 shows the spread of projections. Median values need to be interpreted with caution since they represent a multi-model ensemble. Variation in regional projections across models occurs for all crops and regions. Analyzing uncertainties also allows the detection of robust impacts. In this case, specifically, Northern Africa is the region subject to the largest uncertainties. These uncertainties result from the fact that these countries have very little area suitable for rainfed agriculture and hence small variations in future areas result in large differences in projected relative changes. There is also uncertainty in the Sahel for those crops whose projected impacts are on average positive (groundnut, cassava, pearl millet, sorghum, and yam). These limits in predictability suggest that more research and/or different models are needed in order to better understand climate change impacts, or that a different (e.g. decision-based) approach to climate change adaptation is needed [c.f. Vermeulen et al. (2013)]. Despite these (rather localized) uncertainties in the projections, most of the projected impacts (without adaptation) are robust.

The projections herein analyzed indicate climate change impacts affect crops and regions differently. For some countries (e.g. those along the Sahel), climate change means that most of the crops that are currently climatically suitable can no longer be grown. Indeed, previous studies suggest that in some areas of these countries a livelihood transition from crops to livestock is required (Jones and Thornton, 2009; Thornton *et al.*, 2011). In other cases, a shift to more drought and heat resistant varieties or crops such as cassava, yams, and sorghum could be enough (Jarvis *et al.*, 2012), but this requires planning and investment. For other countries (e.g. Ethiopia, Kenya, and South Africa), climate change might bring opportunities for diversifying cropping and commercializing new crops. Whilst further analyses would be required in order to quantify the economic and nutrition implications of the projections presented here, it is clear that, from a biophysical perspective climate impacts are likely to be severe and adaptation is necessary in order to either reduce future vulnerabilities and capitalize potentially positive impacts. The following section summarizes one such strategy.

An example of adaptation: developing heat-tolerant common beans for East Africa

Adaptation will be needed for most African cropping systems, as a means to either reduce negative impacts or to capitalize any positive effect from climate change. A review of recent literature indicates that the most commonly assessed adaptation strategies include varietal changes and/or crop improvement as well as changes in crop management (i.e. planting date, irrigation timing and amount, and fertilization amounts). Amongst these, changes in planted varieties and, in particular, crop improvement strategies have the potential to fully counter negative impacts of climate change and even boost agricultural productivity (Semenov and Stratonovitch, 2013; Ramirez-Villegas *et al.*, 2015). Recent work on common beans at the International Center for Tropical Agriculture (CIAT) demonstrates the potential of breeding strategies for adapting to climate change (Fig. 7). At CIAT, a heat tolerant accession of tepary bean (*Phaseolus acutifolius*) –a wild relative of common bean (*P. vulgaris*), was used to produce heat tolerant common bean breeding lines (Beebe *et al.*, 2011). Greenhouse experiments revealed that these breeding lines maintain productivity at +3 ºC beyond the current biophysical limits of the crop (S. Beebe, personal communication).

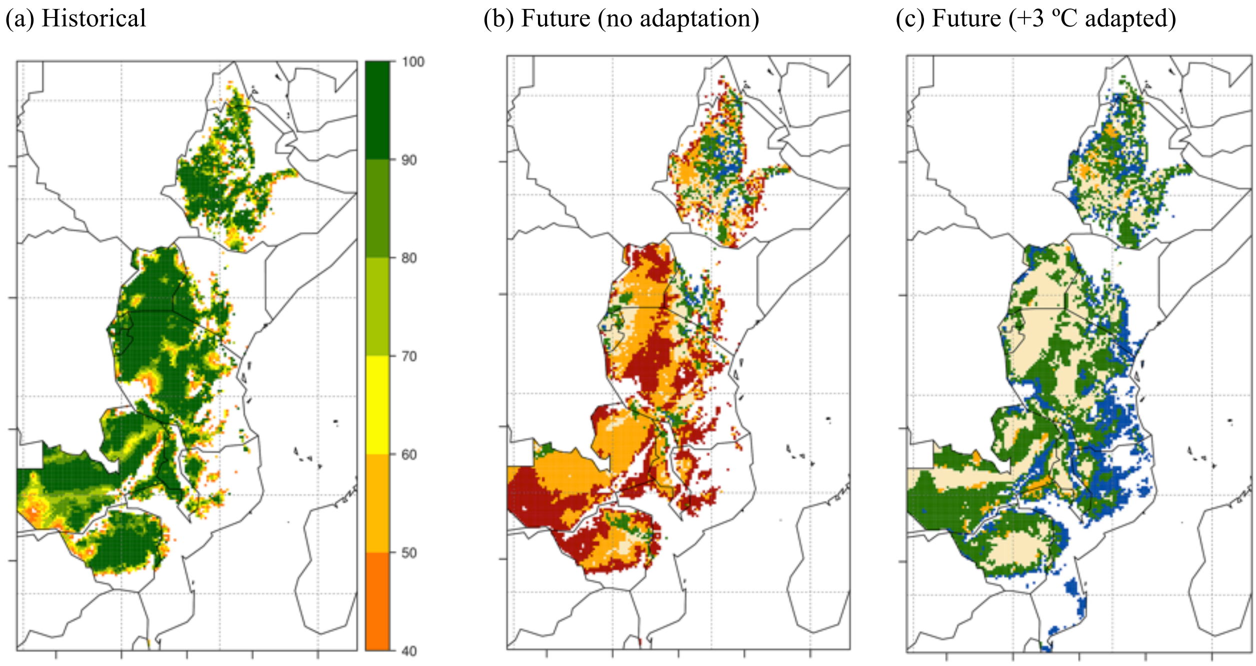


Figure 7: *Historical and future (2050s) common bean suitability simulations for major bean producing areas of East Africa. (a) Suitability of currently cultivated common bean for historical climate; (b): projected impact of climate change for control (no-adaptation) simulations; and (c): projected impact of climate change for adapted common beans. For (b) and (c) panels: red=areas that become unsuitable, orange=areas that remain suitable but reduce their climatic suitability, beige=areas that stay suitable with equal suitability to historical, green=areas that stay suitable but increase their climatic suitability, and blue=new areas (CIAT, unpublished data).*

Put in context, these +3 ºC of heat tolerance are enough to carry East African common beans throughout the entirety of the 21st century under most climate scenarios. Hence, if these breeding lines are further developed to produce market-acceptable varieties, not only suitability and productivity losses can be countered but bean cultivation could also be expanded into new areas in the future (Fig. 7) (CIAT, unpublished data).

Although additional work is required in order to identify the best adaptation strategies, existing literature and recent breeding and experimental results suggest that adaptation is possible. Nonetheless, adaptation will not happen unless investment is made on key research initiatives as well as on scaling mechanisms and incentives to test and adopt the most promising options.

Methods

Climate change impacts are herein based on both a review of recently published studies as well as on CMIP5-based crop model simulations targeted to producing country-level information that is relevant to the SBSTA discussions. The main studies reviewed here are the global meta-analysis of Challinor et al. (2014), as well as the regional meta-analyses of Roudier et al. (2011) [West Africa] and Knox et al. (2012) [all Africa]. In addition to the review of recent literature, regional gridded simulations were analyzed for maize and beans. For maize, the global gridded simulations of Rosenzweig et al. (2014) (available at http://esg.pik-potsdam.de/esgf-web-fe/) were used, whereas for beans new simulations following the same protocol as Rosenzweig *et al*. (2014) were conducted. Furthermore, suitability simulations were conducted with the EcoCrop model (Ramirez-Villegas *et al.*, 2013) in order to project future changes in suitable areas for nine key crops for the region: maize, common bean, cassava, sorghum, yam, finger millet, pearl millet, groundnut, and banana. For coffee, results presented are based on the suitability simulations of Bunn et al. (2014).

EcoCrop was used since it is a simple yet robust niche-based model that uses well-defined optimal and marginal environmental ranges to produce predictions of climatic suitability. As such, the model is relatively easy to parameterize, and yields predictions that are comparable to those of other (more complex) models (Challinor *et al.*, 2015). Using EcoCrop allows the simulation of more crops than those available in more complex process-based models, and therefore allows for more comprehensive analyses. EcoCrop has been used in numerous studies to understand the geography of crop suitability under current and future climates (Lane and Jarvis, 2007; Beebe *et al.*, 2011; Jarvis *et al.*, 2012) as well as to investigate the potential of breeding strategies under future climates (Beebe *et al.*, 2011; Ceballos *et al.*, 2011). Here, suitability simulations for nine key crops listed above were conducted using bias-corrected CMIP5 model output (Hempel *et al.*, 2013). Simulations were conducted for a historical period (1971-2000) and for two future periods: 2050s (2040-2069) and 2080s (2070-2099), for two representative concentration pathways (RCP4.5 and RCP8.5), and using 5 Global Climate Models (GCMs). The two RCPs provide contrasting policy scenarios, and hence help in understanding socio-economic uncertainty, whereas the choice of 5 GCMs provides a realistic representation of the uncertainty associated to the climate system response to greenhouse gas (GHG) forcing.

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