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Climate Change Impacts on Crop Yields in Ethiopia

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

We present results of model simulations of maize, wheat, and sorghum yields in Ethiopia through 2085. The analysis draws on climate outcomes from 32 global climate models and an agronomic crop model to estimate effects on the yields of these cereals of expected higher temperatures and, for most of Ethiopia, increased rainfall. The simulation results suggest that climate change will likely have only relatively small effects on average yields of maize, wheat, and sorghum in Ethiopia up to 2055, as agronomic conditions for cultivation of these crops may actually improve in large parts of the country. Nonetheless, yields will need to increase over time to enable cereal production to keep pace with expected demand growth due to increases in population and per capita incomes. Moreover, even if future changes in climate have only moderate impacts on *average* crop yields in Ethiopia, there is growing evidence that weather outcomes are likely to become more variable in the future, implying that severe droughts and floods may very well have a greater impact on cereal production in the future than in the past.

1. INTRODUCTION

It is commonly thought that climate change is likely to have major effects on Ethiopian agriculture and the country's overall development over the next fifty years and beyond. Indeed, each of the 32 major climate change models used in our analysis indicate a high probability of significant increases in average world temperatures by 2055, as well as an increase in median temperatures in Ethiopia. The prognosis for rainfall in Ethiopia is much less certain, although on average the simulation models suggest a relatively small increase in rainfall for the country overall. Moreover, there is a growing consensus that climate variability will increase in all regions of the world (IPPC 2018).

Earlier studies of the likely effects of climate change in Ethiopia point to both positive and negative effects. Studies of the effects of climate change on water flow (Dile et al. 2013, Wagena et al. 2016) generally suggest significant increases in water availability with potential benefits for irrigation, as well as increases in variability and flooding (Taye et al. 2015, Nawaz et al. 2010, Kim et al. 2008, Kim and Kaluarachchi 2009).[1] Robinson et al. (2012) examined potential effects on water flows, crops, infrastructure, and economic output, concluding that, in the absence of adaptation investments, Ethiopia's GDP in 2050 would be up to 10 percent below the counterfactual no climate change baseline. [2] More recently, Admassu et al. (2013) used a crop model to project climate effects on key crops in Ethiopia between 2000 and 2050. Based on output of three climate models, their analysis shows yield gains of over 25 percent in much of the eastern highlands and north-central highlands, but large yield reductions and loss of areas suitable for growing maize in the eastern and southwestern parts of central Ethiopia.[3]

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[1] In their analysis of the upper Blue Nile basin for 2010-2100, Dile et al. (2013) find that climate change may result in an annual increase in flow volume for the Gilgel Abay River, benefitting local small-scale irrigation activities. Likewise, Wagena et al. (2016) used watershed models to analyze water flows in the highlands of the Blue Nile Basin for two periods (2041–2065 and 2075–2099) based on four climate scenarios from six climate models. Their results indicate that the Tana and Beles basins will have large (22-27 percent) increases in mean annual flow, as well as 16 to 19 percent increases in sediment concentrations, with potentially large net benefits for hydropower generation.

[2] Robinson et al. (2012) used a system of hydrology, crop, road, and other models to simulate the possible effects of changes in precipitation and temperature as reflected in projections from four of 22 global climate models available at the time of the study. Unlike the main analysis here, which is based on the average results from a set of 31 global climate models, the Robinson et al. analysis was designed to provide an estimate of the range of outcomes, so was based on four extreme projections: the wettest and driest projections on a global scale, and the wettest and driest projections for Ethiopia. Agricultural GDP is highest under the driest global climate projection, but falls in other projections, in part due to damage from extreme floods in some years.

[3] In these simulations, maize yields rise through 2020 before leveling off between 2020 and 2050. Rainfed wheat yields generally decline in response to climate change, with one of the climate models Admassu et al. used showing large losses. The crop model results for sorghum are very similar to those for maize.

This paper presents a further analysis of the potential effects of projected climate change scenarios for cereal crop yields in Ethiopia in 2035, 2055, and 2085. The methodology used in determining the direct effect of climate on crop yields (described in detail below) is similar to that of Admassu et al. (2013), but differs in using agro-ecological zones more closely corresponding to cropping patterns in Ethiopia, as well as by drawing on the results of a wider array of climate models. In particular we utilize coefficients from regressions of simulated yields from a crop simulation model, the Decision Support System for Agrotechnology Transfer (DSSAT) crop systems model, with climate variables as explanatory variables.

In the rest of this paper, we first summarize the results of the major climate models for rainfall and temperature across six main agro-ecological zones in Ethiopia. Thereafter, we present results of the crop yield models for three of the major cereal crops in Ethiopia: wheat, maize, and sorghum. (Unfortunately, no crop model is available for teff.) In the third section, we construct long-term yield growth trends consistent with historical yield growth and yield gaps between Ethiopia and comparator countries in sub-Saharan Africa. The last section presents a brief summary and conclusions.

2. CLIMATE CHANGE SCENARIOS: RAINFALL AND TEMPERATURE PROJECTIONS FOR ETHIOPIA

Our analysis draws on temperature and rainfall outcomes from simulations of 32 downscaled global climate models for 2035, 2055, and 2085[4] (Ramirez and Jarvis 2008). We use the simulated monthly means of rainfall and temperature by 5 arc minute grid cells (pixels equivalent in size to about 9 km x 9 km at the equator) from each global climate model. We then use the absolute deviations from the mean temperature and rainfall from each of the 31 years (1980 to 2010) from the AgMERRA database (Ruane, Goldberg, and Chryssanthacopoulos 2015) to generate a set of 992 (32 x 31) simulated temperature and rainfall outcomes for each of the grid cells that encompass Ethiopia for each of the three simulation years (2035, 2055, and 2085).[5]

Thus, for global climate model m, mean rainfall for simulation year T, grid cell I, and climate realizations j, is calculated as:

$$R(m,i,t,T) = r(m,i,T) + e(i,t),$$

where T = simulation year 2035, 2055, or 2085

$R(m,i,t,T)$ = simulated value of rainfall (or temperature) from model m for gridcell i and year T using climate realization t,

$r(m, i,T)$ = mean (or median) simulated value of rainfall (or temperature) from model m for grid cell i and year T, and

$e(i,t)$ = deviation from mean rainfall (or temperature) from historic climate realization from 1980-2010, (t=1,31).

Table 2.1 presents the results for rainfall and temperature for the six agro-ecological zones in Ethiopia defined in Schmidt and Thomas (2018). As a base for comparison, we use the average climate conditions for the period 1960 to 1990 from WorldClim (v. 1.4). Taken together, the outputs from these 32 climate models suggest that Ethiopia will likely have a moderate increase in rainfall in all agro-ecologies in the main growing season (May to October), with a median increase in precipitation of 39 millimeters above the mean precipitation of 595 millimeters in the 1960 to 1990 period. The mean daily maximum temperatures of the warmest month in the main growing season (May to October), however, are likely to be considerably

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[4] Throughout this paper, 1975 may be used as a shorthand notation for averages for the 1960-1990 period; 2013 for averages for the 2012-2015 period; 2035 for averages for the 2020-2049 period; 2055 for averages for the 2040-2060 period; and 2085 for averages for the 2070-2099 period. The latter three periods are based on Ramirez-Villegas and Jarvis (2010).

[5] Note that this procedure implicitly assumes that the distribution of percentage deviations from mean temperature and rainfall realizations from the 1980 to 2010 period remains the same for future periods.

higher than in the base period, with a median increase of 2.6 °C. This increase is approximately equal to the median temperature increase value for Eastern Africa, but less than the global median temperature increase.

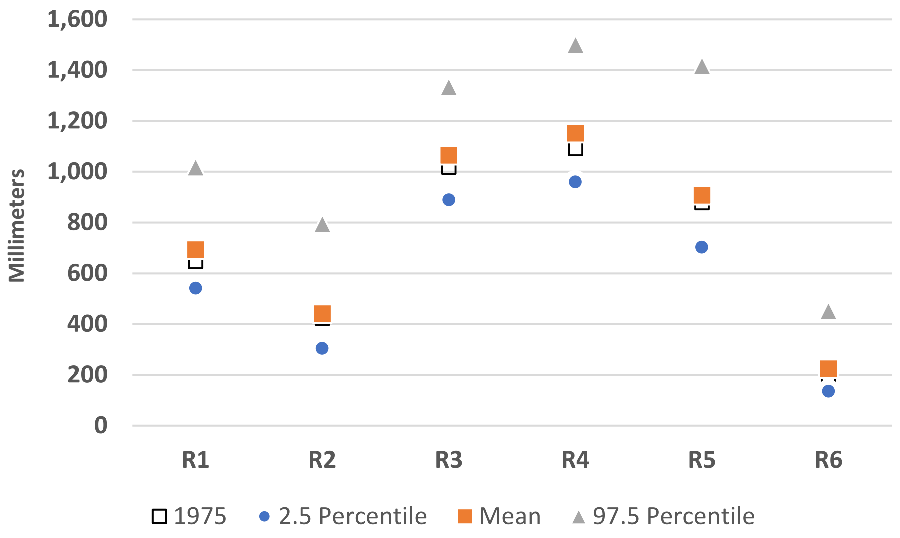
Table 2.1. Projections of temperature and rainfall changes in Ethiopia between 1975 and 2055

	Precipitation (millimeters), May to October				Mean daily maximum temperature, warmest month (^{0}C), May to October			
		Change between 1960-1990 and 2041-2070				Change between 1960-1990 and 2041-2070		
Agro-ecological zone	**Mean for 1960-1990**	**2.5 percent-ile**	**Median**	**97.5 percent-ile**	**Mean for 1960-1990**	**2.5 percent-ile**	**Median**	**97.5 percent-ile**
Drought prone, highland	646	-106	47	372	29.0	0.4	2.9	5.4
Drought prone, lowland	423	-119	18	373	29.3	0.7	2.5	4.5
Humid moisture reliable, lowland	1,018	-130	46	317	34.1	0.2	2.7	4.3
Moisture reliable, highland-cereal	1,091	-132	60	410	26.7	0.3	2.6	4.7
Moisture reliable, highland-enset	878	-176	29	540	26.4	0.4	2.4	4.3
Pastoralist	193	-58	31	259	34.3	1.1	2.6	4.5
Ethiopia	595	-112	39	355	31.0	0.7	2.6	4.7

Source: Authors' calculations.
Notes: The tables summarize the results of simulations of 32 global climate models. (See text.)
The data shown are unweighted averages of precipitation and rainfall across grid cells for each agro-ecological zone.

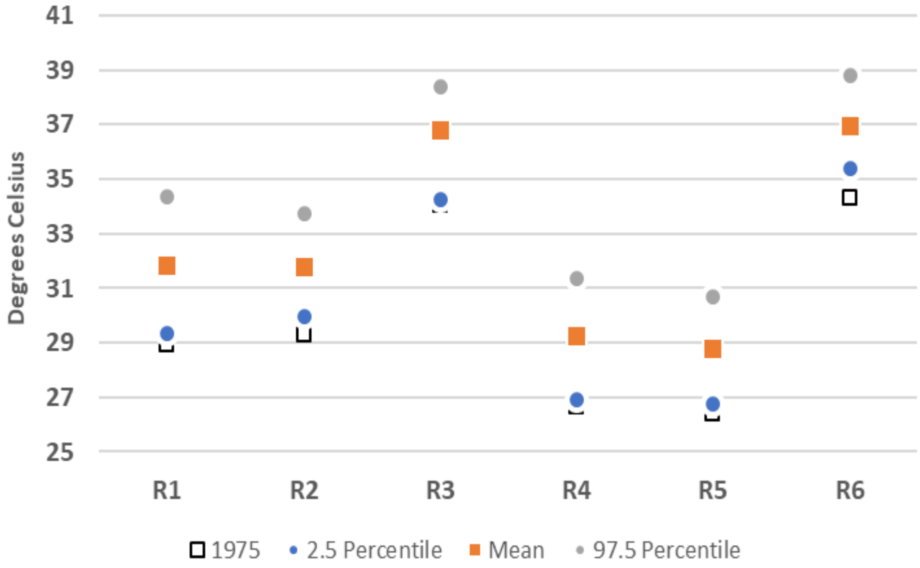
The largest absolute increases in mean daily maximum temperatures are expected to be in the drought prone highlands – a median increase of 2.9 °C, from 29.0 °C in the 1960 to 1990 period to 31.9 °C in the 2014 to 2070 period (Figure 2.1). Likewise, this agro-ecological zone has the largest extreme temperature gains, with an increase of 5.4 °C in the top 2.5 percent of the temperature distribution across the sample of model simulations (Figure 2.2).

Figure 2.1. Ethiopia: Simulated rainfall in 2055 by agro-ecological zone



Source: Authors' calculations from climate model simulations.
Note: R1 = Drought prone, highland; R2 = Drought prone, lowland; R3 = Humid moisture reliable, lowland; R4 = Moisture reliable, highland – cereal; R5 = Moisture reliable, highland – enset; R6 = Pastoralist. The year 2055 is the middle year of the 2041-2070 period, on which the climate data is based.

Figure 2.2. Ethiopia: Simulated temperature in 2055 by agro-ecological zone



Source: Authors' calculations from climate model simulations.
Note: R1 = Drought prone, highland; R2 = Drought prone, lowland; R3 = Humid moisture reliable, lowland; R4 = Moisture reliable, highland – cereal; R5 = Moisture reliable, highland – enset; R6 = Pastoralist. The year 2055 is the middle year of the 2041-2070 period, on which the climate data is based.

3. POTENTIAL EFFECTS OF CLIMATE CHANGE ON MAIZE, WHEAT, AND SORGHUM YIELDS

To estimate the effects of climate change on crop yields, we employ results of simulations using the Decision Support System for Agrotechnology Transfer (DSSAT) suite of crop models.[6] We use yields calculated by DSSAT along with the corresponding weather input into those models to estimate parameters in a regression that describe how weather variables and other important agronomic variables influence yield. We then take these regression parameter estimates and use them to estimate the effects of simulated climate change outcomes on yields.

Yield effects in DSSAT are calculated for each 9 km by 9 km grid cell in a geographic grid under purely rainfed conditions. In our work with DSSAT, we use monthly weather inputs which DSSAT then converts to daily weather using an internal weather simulator. For this exercise, we feed into DSSAT rainfall and temperature outcomes from the HadGEM2_ES global climate model (Collins et al. 2011, Martin et al. 2011) and under the RCP8.5 high emissions scenario for the 2041 to 2070 period and for the 2071 to 2099 period, as well as for historical climate data from 1960 to 1990. Doing so gives us a wide range of values for the regression (ranging from no climate change to a very large climate change represented by the HadGEM2_ES model at the end of the century).[7] A wide range of climate values helps us to ensure that the parameter estimates provide a good fit for feasible values spanning more than a century.

Using the output from the DSSAT model, the yield of crop *c* (wheat, sorghum, *meher* season maize, or *belg* season maize) planted on soil type *s* in grid cell *i*[8] under model simulation *ms* is estimated as follows:

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[6] DSSAT is a suite of single crop models (Hoogenboom et al. 2012, Jones et al. 2003). Yields are estimated using site-specific weather data during the growing season, soil data, and management practices.

[7] Note that the yield calculations ignore possible carbon dioxide fertilization effects.

[8] Because more spatially disaggregated data are not available, we assume that the soil type, rainfall and temperature are uniform within each grid cell.

$$\begin{aligned} Yield(c,i,ms) = {} & \alpha_0(c) + \alpha_1(c)*\mathrm{elev}(i) + \alpha_2(c)*\mathrm{elev}(i)^2 + \alpha_3(c)*N(i) + \alpha_4(c)*N(i)^2 + \textstyle\sum_{s=0}^{12}[\,\alpha_{5s}(c)*D(s,i)] \\ & + \textstyle\sum_{m=0}^{3}[\beta_{1m}(c)*rain(i,m,ms) + \beta_{2m}(c)*rain(i,m,ms)^2 + \beta_{3m}(c)*rain(i,m,ms)^3 \\ & + \beta_{4m}(c)*temp(i,m,ms) + \beta_{5m}(c)*temp(i,m,ms)^2 + \beta_{6m}(c)*temp(i,m,ms)^3 \\ & + \beta_{7m}(c)*rain(i,m,ms)*temp(i,m,ms) + \beta_{8m}(c)*rain(i,m,ms)^2*temp(i,m,ms) \\ & + \beta_{9m}(c)*temp(i,m,ms)^2*rain(i,m,ms)] + e(c,i,ms), \end{aligned}$$

where *rain(i,m,ms)* and *temp(i,m,ms)* are total rainfall and mean daily maximum temperature, respectively, for grid cell *i* and model simulation *ms*; *m* indexes the month during the growing season (with 0 being the planting month, 1 the month after the planting month, etc.); *elev* is the elevation of grid cell *i*; *N* is the starting nitrogen level for the soil in grid cell *i*; and *D(s,i)* is a categorical value of 1 if the soil in grid cell i is of type *s* and 0 otherwise. Parameters from this regression are then used to estimate yields for each crop for each 9 km x 9 km grid cell across Ethiopia using the rainfall and temperature outcomes from all 32 global climate models for each of 31 weather realizations.

For each pixel and crop, the DSSAT algorithm searches for the planting month that gives the highest yield based on the prediction from the regression, with the constraint that the planting month has to align with those recognized as feasible by agronomic professionals that work with Ethiopian agriculture.

Average yield changes for each of Ethiopia's six agro-ecological zones are calculated using weights from the spatially disaggregated estimates of area cultivated for each crop from IFPRI's Spatial Production Allocation Model (SPAM); (You, Wood, and Wood-Sichra 2006, You et al. 2014).

3.1 Implications of climate change on crop yields

Overall, the simulated net effects of increases in average rainfall and higher average temperatures are relatively small. Simulated maize yields are higher on average in the climate change simulations, with average yields 1.2 and 4.2 percent higher than 2013 yields in 2035 and 2085, respectively (Table 3.1; Figure 3.1; Figure 3.2). Average wheat yields are only 0.3 percent lower in 2035 than in 2013, and only 1.1 and 2.7 percent lower by 2055 and 2085, respectively, than in 2013 (Table 3.1; Figure 3.1; Figure 3.3). Sorghum yields in 2035 and 2055 are 0.6 percent higher than in 2013; by 2085, however, sorghum yields are 0.9 percent lower than in 2013 (Table 3.1; Figure 3.1; Figure 3.4).

Table 3.1. Ethiopia: Simulated crop yields with climate change

	2013	2035	2055	2085
Maize				
Yield: Climate change with no technical change, kg/ha [a]	3,372	3,414	3,460	3,515
Climate change effect, relative to 2013, %	----	1.2	2.6	4.2
Yield: Technical change only, kg/ha [b]	3,372	4,644	6,255	9,777
Cumulative technical change, relative to 2013, %	----	38.8	86.9	192.1
Yield: Technical change with climate change, kg/ha	3,372	4,702	6,418	10,191
Cumulative technical change with climate change, %	----	40.5	91.8	204.5
Wheat				
Yield: Climate change with no technical change, kg/ha [a]	2,475	2,467	2,447	2,409
Climate change effect, relative to 2013, %	----	-0.3	-1.1	-2.7
Yield: Technical change only, kg/ha [b]	2,475	3,065	3,740	5,041
Cumulative technical change, relative to 2013, %	----	23.9	51.1	103.7
Yield: Technical change with climate change, kg/ha	2,475	3,056	3,698	4,908
Cumulative technical change with climate change, %	----	23.5	49.4	98.3
Sorghum				
Yield: Climate change with no technical change, kg/ha [a]	2,336	2,350	2,349	2,314
Climate change effect, relative to 2013, %	----	0.6	0.6	-0.9
Yield: Technical change only, kg/ha [b]	2,336	2,893	3,530	4,758
Cumulative technical change, relative to 2013, %	----	23.9	51.1	103.7
Yield: Technical change with climate change, kg/ha	2,336	2,911	3,550	4,714
Cumulative technical change with climate change, %	----	24.6	52.0	101.8

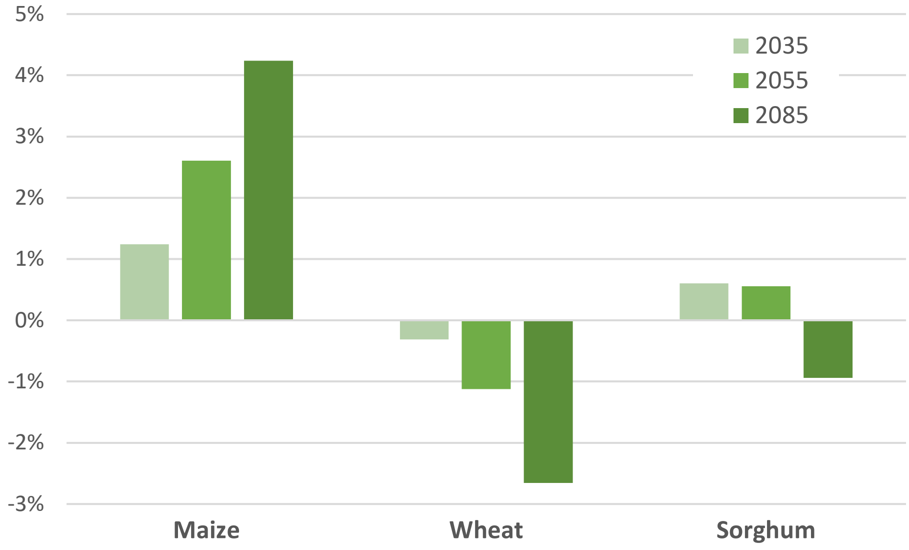
Source: Authors' calculations from model simulations.

Notes:

[a] Based on average of actual yields for 2012 to 2015 (FAO 2019) and percentage changes from climate model simulations. (See text.)

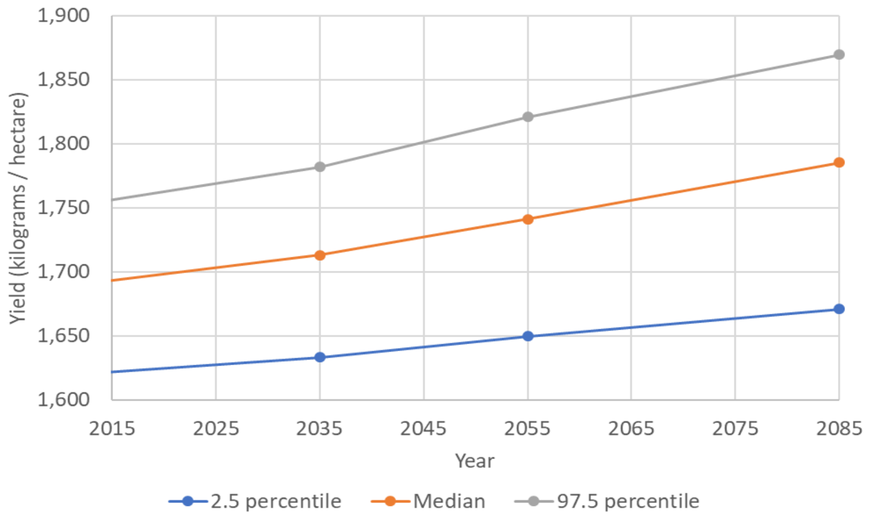
[b] Using assumed yield annual growth rates (maize 1.5%, wheat 1.0%, sorghum 1.0%).

Figure 3.1. Ethiopia: Simulated climate change impacts on crop yields relative to 2013 yields



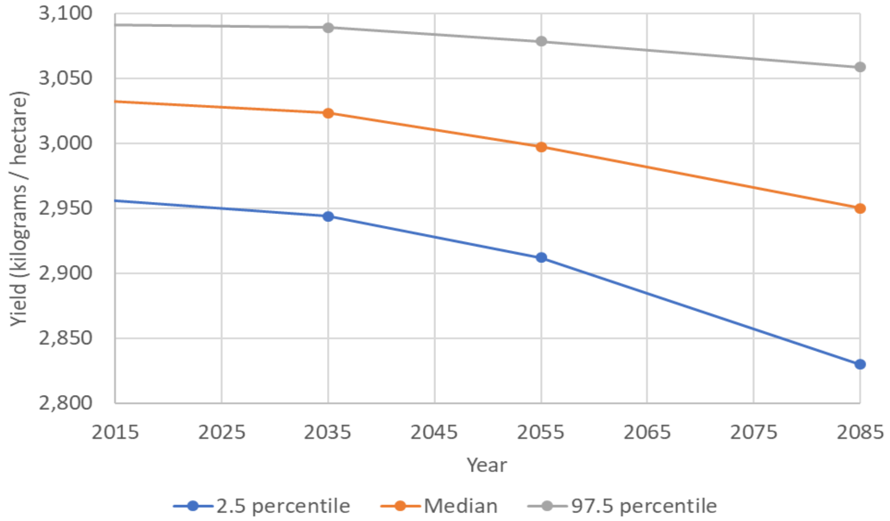
Source: Authors' calculations from model simulations.

Figure 3.2. Ethiopia: Simulated climate change impacts on maize yields, 2015 to 2085



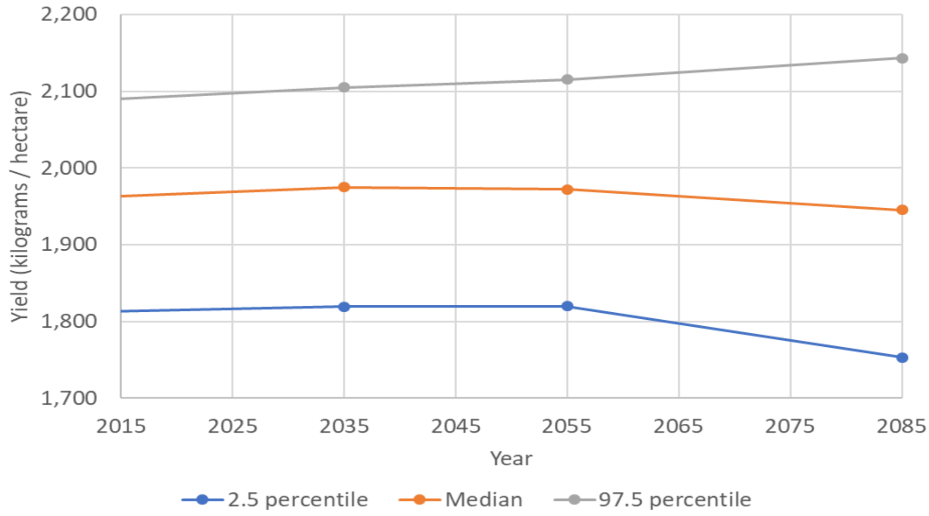
Source: Authors' calculations.

Figure 3.3. Ethiopia: Simulated climate change impacts on wheat yields, 2015 to 2085



Source: Authors' calculations.

Figure 3.4. Ethiopia: Simulated climate change impacts on sorghum yields, 2015 to 2085



Source: Authors' calculations.

Moreover, the simulated effects of climate change on yields vary somewhat across regions. For maize, median maize yields in the three highland agro-ecological zones in 2035 are 2.7 to 5.0 percent higher than average yields in the 1960 to 1990 period, but only 0.6 to 1.5 percent higher in the two lowland agro-ecological zones (excluding the pastoralist zone) (Table 3.2). Median wheat yields are lower in each region, ranging from -0.3 percent in the drought prone highlands to -1.9 percent in the drought prone lowlands in 2035 (Table 3.3). Sorghum yields vary most across regions, with median yields in 2035 having fallen sharply by 6.2 percent due to climate change in the humid moisture-reliable lowlands, but rising in all other regions by between 1.4 and 3.7 percent (Table 3.4).

Table 3.2. Simulated climate change effects on maize yields by agro-ecological zone in Ethiopia, relative to 2013 yields, percent

	Drought prone, highland	Drought prone, lowland	Humid moisture reliable, lowland	Moisture reliable, highland-Cereal	Moisture reliable, highland-Enset	Pastoralist	Ethiopia
2035							
P2.5	0.0	-1.5	0.3	1.1	-0.5	-0.4	0.8
P25	1.2	0.2	0.3	1.3	0.6	0.2	1.2
Median	1.8	0.5	0.2	1.3	1.0	0.9	1.3
P75	1.7	1.3	0.5	1.4	1.7	1.6	1.4
P97.5	2.4	1.6	0.4	1.7	2.3	2.8	1.6
2055							
P2.5	-0.8	-4.8	0.1	2.4	-0.8	-2.3	1.8
P25	2.3	-0.4	0.2	3.0	1.7	0.0	2.8
Median	3.2	0.9	0.3	3.1	2.3	1.5	2.9
P75	3.2	3.0	0.6	3.4	3.6	2.4	3.1
P97.5	5.1	3.9	0.7	4.1	4.9	5.8	3.8
2085							
P2.5	-1.2	-8.5	-2.7	4.6	-1.1	-5.0	3.1
P25	3.9	-0.9	-0.8	5.4	3.8	-0.7	5.2
Median	5.5	2.8	-0.5	5.7	5.6	1.9	5.5
P75	6.6	6.6	0.0	6.0	7.2	5.5	6.0
P97.5	9.0	8.7	0.9	7.3	9.1	10.5	6.6

Source: Authors' calculations from model simulations.

Notes: Percentage changes from climate model simulations (see text). Baseline yield values were computed from observed climate data for 1960-1990 and from model projections for 2020-2039, then interpolated to 2012-2015. P2.5 = 2.5 percentile level of climate model simulation yield results; P25 = 25th percentile; P75 = 75th percentile; P97.5 = 97.5 percentile.

Table 3.3. Simulated climate change effects on wheat yields by agro-ecological zone in Ethiopia, relative to 2013 yields, percent

	Drought prone, highland	Drought prone, lowland	Humid moisture reliable, lowland	Moisture reliable, highland-Cereal	Moisture reliable, highland-Enset	Pastoralist	Ethiopia
2035							
P2.5	-0.1	-1.4	-0.8	-0.5	-1.1	-0.9	-0.4
P25	-0.2	-1.0	-0.6	-0.4	-0.6	-0.4	-0.3
Median	-0.1	-0.7	-0.4	-0.3	-0.6	-0.6	-0.3
P75	-0.1	-0.4	-0.4	-0.3	-0.5	-0.2	-0.3
P97.5	0.2	-0.2	0.3	-0.1	-0.3	-0.2	-0.1
2055							
P2.5	-0.3	-4.0	-2.5	-1.7	-2.8	-2.4	-1.5
P25	-0.9	-2.5	-1.8	-1.4	-2.2	-1.4	-1.2
Median	-0.6	-1.7	-1.1	-1.2	-1.8	-1.4	-1.2
P75	-0.6	-1.1	-0.7	-1.0	-1.4	-0.7	-1.0
P97.5	0.2	-0.5	-0.8	-0.5	-0.9	-0.6	-0.4
2085							
P2.5	-1.8	-5.8	-5.3	-4.5	-7.1	-3.4	-4.3
P25	-2.5	-4.1	-3.9	-3.5	-4.9	-2.5	-3.2
Median	-2.0	-3.1	-2.6	-2.8	-3.9	-2.3	-2.7
P75	-1.3	-2.2	-1.3	-2.2	-3.2	-0.9	-2.1
P97.5	0.0	-1.3	-0.1	-1.1	-1.7	-0.5	-1.1

Source: Authors' calculations from model simulations.
Notes: Percentage changes from climate model simulations (see text). Baseline yield values were computed from observed climate data for 1960-1990 and from model projections for 2020-2039, then interpolated to 2012-2015. P2.5 = 2.5 percentile level of climate model simulation yield results; P25 = 25th percentile; P75 = 75th percentile; P97.5 = 97.5 percentile.

Table 3.4. Simulated climate change effects on sorghum yields by agro-ecological zone in Ethiopia, relative to 2013 yields, percent

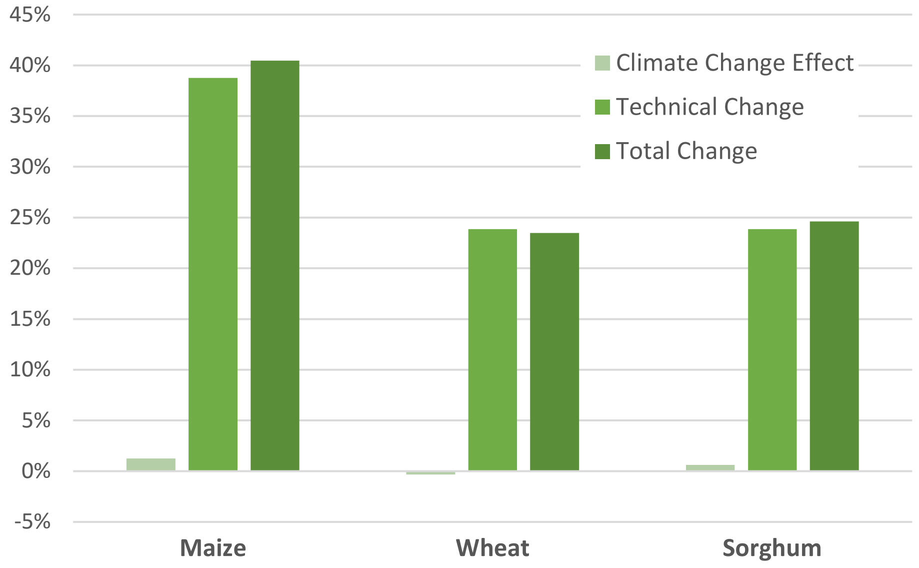
	Drought prone, highland	Drought prone, lowland	Humid moisture reliable, lowland	Moisture reliable, highland-Cereal	Moisture reliable, highland-Enset	Pastoralist	Ethiopia
2035							
P2.5	0.4	1.0	-3.3	1.3	0.1	0.6	0.4
P25	0.6	1.0	-2.9	1.4	0.8	0.8	0.5
Median	0.8	1.1	-2.3	1.3	0.9	0.5	0.6
P75	0.7	1.3	-1.2	1.4	1.4	1.1	0.6
P97.5	1.6	1.7	-0.7	1.7	2.3	1.7	0.8
2055							
P2.5	0.1	1.0	-10.1	2.8	1.3	-0.1	0.4
P25	0.3	1.7	-8.8	2.8	1.9	0.4	0.4
Median	0.8	1.8	-6.9	2.6	2.0	0.6	0.5
P75	0.5	2.0	-4.9	2.7	2.5	1.3	0.7
P97.5	2.5	4.1	-2.9	3.3	6.2	3.0	1.3
2085							
P2.5	-4.7	0.4	-25.2	2.8	1.6	-3.7	-3.3
P25	-2.2	1.8	-19.3	3.1	2.8	-1.2	-2.1
Median	-0.6	2.3	-16.0	3.4	3.0	-0.3	-0.9
P75	-0.3	2.8	-12.5	3.8	3.7	2.1	-0.5
P97.5	4.4	7.4	-1.9	5.2	11.5	5.6	2.6

Source: Authors' calculations from model simulations.
Notes: Percentage changes from climate model simulations (see text). Baseline yield values were computed from observed climate data for 1960-1990 and from model projections for 2020-2039, then interpolated to 2012-2015. P2.5 = 2.5 percentile level of climate model simulation yield results; P25 = 25th percentile; P75 = 75th percentile; P97.5 = 97.5 percentile.

3.2 Implications of technical change coupled with climate change on crop yields

Given that cereal yields in Ethiopia are considerably lower than those in most developed countries, there is substantial potential for technical change through increased use of improved seeds and fertilizer and better water management to lead to significant increases in cereal yields over time (van Ittersum et al. 2016). Maize, wheat, and sorghum yields increased by 4.6, 7.2, and 2.3 percent per year, respectively, over the 2010/11 to 2015/16 Ethiopian calendar years.[9] Further yield increases of this magnitude are not likely, however, so we model a much more moderate growth in yields due to technical change of 1.5 percent per year for maize and 1.0 percent per year for wheat and sorghum. Under these assumptions, technical change (with no climate change) would result in a 38.8 percent increase in maize yields between 2013 and 2035; wheat and sorghum yields would each increase by 23.9 percent (Table 3.1; Figure 3.5).

Figure 3.5. Ethiopia: Simulated yields in 2035 with technical change and climate change relative to 2013 yields



Notes: Yields estimated from percentage changes in yields from climate change model simulations.
Source: Authors' calculations from model simulations.

Even with these rather modest rates of yield gains from technical change, the effects of technical change are far greater than the effects of climate change, so that average yields of these maize, wheat and sorghum overall, taking into account the effects of climate change on yields, will increase by 40.5, 23.5, and 24.6 percent, respectively, between 2013 and 2035 (Table 3.1; Figure 3.5). By 2055, the total yield gains would be substantially larger -- 91.8 percent for maize; 49.4 for wheat, and 52.0 percent for sorghum.

4. SUMMARY AND CONCLUSIONS

The model simulations suggest that climate change will likely have only relatively small effects on average yields of maize, wheat, and sorghum in Ethiopia in 2035 and even in 2055. Although temperatures are expected to increase, average rainfall is also expected to increase in most regions of the country. Thus, agronomic conditions for cultivation of these crops may actually improve in large parts of the country, especially the highlands, that currently have moderate average temperatures.

Nonetheless, crop yields will need to increase to enable cereal production to keep pace with expected demand growth due to increases in population and per capita incomes. This in turn will require continued public and private investments in agriculture and rural infrastructure, as well as policies that maintain

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[9] These calculations are based on Central Statistical Agency (CSA) data. Note that the Ethiopian calendar years begins and ends in mid-September.

incentives for modern input use and adoption of new technology. These investments and policies are particularly important because in many parts of the country land degradation is reducing yields, necessitating further investments in sustainable land management, as well as increased fertilizer use to enable even moderate yield gains (Schmidt et al. 2017).

Moreover, even if future changes in climate have only moderate impacts on *average* crop yields in Ethiopia, there is growing evidence that weather outcomes, particularly rainfall, are likely to become more variable in the future. For example, Pendergrass et al. 2017, suggest that precipitation variability over land rises by 4 to 5 percent for every degree Celsius increase in temperature. Thus, there could still be substantial effects on crop production and household welfare (as well as on livestock) due to extreme events – droughts, floods, or extremely high temperatures. The findings presented in this paper are no cause for complacency in Ethiopian agriculture in the face of climate change.

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The Ethiopia Strategy Support Program is an initiative to strengthen evidence-based policymaking in Ethiopia in the areas of rural and agricultural development. Facilitated by the International Food Policy Research Institute (IFPRI), ESSP works closely with the government of Ethiopia, the Ethiopian Development Research Institute (EDRI), and other development partners to provide information relevant for the design and implementation of Ethiopia's agricultural and rural development strategies. For more information, see http://www.ifpri.org/book-757/ourwork/program/ethiopia-strategy-support-program; http://essp.ifpri.info/; or http://www.edri-eth.org/.

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