CHAPTER 6

The Impact of Climate Change on Agriculture

Timothy S. Thomas

Introduction

Agriculture is an extremely important sector for Africa, providing a large contribution to GDP in most countries and, more importantly, representing a key source of employment in most of the continent—including 52 percent in Africa south of the Sahara in 2022 (International Labour Organization 2024)—while also serving as a bulwark against household food insecurity. Agriculture, however, is the sector most exposed to climate risk, and in years when climate conditions are not favorable, the resulting lower-than-normal agricultural production contributes to increases in food insecurity in almost every country on the continent.

Climate change is disrupting historical climate patterns, potentially worsening productivity in many locations and also potentially increasing the variability of seasonal precipitation. Changes in rainfall patterns could result in longer droughts or more frequent and severe flooding in addition to increased unpredictability. Longer droughts cause consecutive low-production years and can also impact hydroelectric power generation. Floods can wash away or inundate crops and can also wash away roads and bridges, disrupting market connections for farmers.

Higher temperatures associated with climate change can drive down yields in places where the temperature is already at or above the optimal temperature for the crops grown there, through direct, abiotic impacts on crop growth and through biotic impacts, with pests and diseases potentially causing both pre- and postharvest losses. Higher temperatures can also lower the productivity of labor devoted to agriculture, lower the productivity of livestock (meat, milk, and eggs), and increase livestock mortality and morbidity.

But despite its considerable potential harmful impacts, climate change could turn out to be relatively neutral or even positive in some locations, for several reasons. First, much agricultural activity occurs in cooler parts of countries, where rising temperatures could increase yields. Second, precipitation may increase in many locations, potentially enhancing yields where irrigation is not available and where rainfall has historically been less than optimal. Finally, while the theory is still scientifically controversial, many scientists believe that yields of C3 crops (all crops except the C4 crops: maize, sorghum, millet, teff, sugarcane, and some grasses) will benefit from higher levels of CO_2 in the atmosphere (commonly called "CO_2 fertilization"). C4 crops could potentially see very small boosts in yield from CO_2 fertilization.

This chapter examines the likely impact of climate change on African agriculture between now and 2050, presenting modeled results for the continent and the five subregions, drawing from crop and bioeconomic models that use multiple climate models as inputs. The chapter focuses on the impact of climate change on the major crops for the continent and each subregion. The second section briefly describes the models used in this chapter. The third section presents the key agricultural commodities for the continent and each subregion. The fourth section briefly describes Africa's climate along with the climate change that has been observed already. The fifth section provides the details of the climate models used. The sixth section focuses on the crop model results for Africa, showing the effect on seven different crops. The seventh section presents the results of the bioeconomic model, which considers how climate change affects other countries, in particular the comparative advantages of Africa under climate change. The final section provides concluding remarks.

Overview of Models Used in This Chapter

The description in this section draws on a similar description in Thomas and Robertson (2024), which focuses on eastern and southern Africa.

ISIMIP Climate Models

Every six to eight years, the Intergovernmental Panel on Climate Change (IPCC) produces a major synthesis of the current understanding of the science of climate change and the impact of climate change on the world. The latest iteration is known as the Sixth Assessment Report (AR6), a multivolume work whose first volume was published in 2021. As part of each assessment cycle, climate modeling teams from around the world produce their projections for future climates under specific greenhouse gas (GHG) emissions scenarios.

The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) is an international network of modelers investigating the impact of climate change on multiple sectors. ISIMIP produces climate and socioeconomic datasets that can be used for consistent analysis across sectors. ISIMIP selected five of the climate models from those submitted for the IPCC's AR6 and downscaled them (Lange 2021) to half-degree pixels (approximately 50 kilometers on edge) that are useful for agricultural modeling. The climate models chosen by ISIMIP and AgMIP (the agricultural modeling group within ISIMIP) as representative models from CMIP6 (climate models from AR6) are GFDL-ESM4 (GDFL), IPSL-CM6A-LR (IPSL), MPI-ESM1-2-HR (MPI), MRI-ESM2-0 (MRI), and UKESM1-0-LL (UK).

The climate models are available for three different emissions scenarios, called representative concentration pathways (RCPs), designated by 2.6, 7.0, and 8.5, which represent the number of watts per square meter of radiative forcing in 2100 caused by GHGs in the atmosphere in 2100. This study focuses on the highest emissions scenario, RCP8.5, as an upper bound. Through 2050, it is very similar to RCP7.0, and therefore the modeling results are also similar (after 2050, the growth rate of GHGs under the RCP7.0 scenario tapers relative to that under RCP8.5).

DSSAT Crop Model

This study uses the Decision Support System for Agrotechnology Transfer (DSSAT) software to model the effect of climate on yields (DSSAT 2024; Hoogenboom et al. 2019; Jones et al. 2003). DSSAT is a well-documented and well-respected modeling tool. Aggregated monthly averages for a baseline climate of 2005 and future climates as projected by the five CMIP6 global climate models under RCP8.5 are input into the DSSAT weather simulator. The weather simulator generates daily weather consistent with the defined monthly climate aggregate. Multiple simulated daily weathers are generated at each pixel, yields are computed for them, and then the yields are averaged across the multiple simulations to generate the yield that is typical for that pixel and crop under that climate. DSSAT yields and yield changes are mapped and examined for geographic and quantitative consistency and smoothness. The simulation uses the resolution of the climate datasets. That is, the crop model makes projections for yield impact at every half-degree pixel, which is the standard resolution for most global studies of climate impact on agriculture. Calibration of yield levels is not necessary because the analysis considers yield changes over time due to climate change and not absolute values. Seven crops are modeled in the DSSAT: maize, sorghum, rice, groundnuts, wheat, soybeans, and potatoes.

IMPACT Bioeconomic Model

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which has been used since the mid-1990s to study future global supply, demand, and trade in the agriculture and food sector, has climate change embedded as a fundamental component. Details of the model can be found in Robinson and colleagues (2024). IMPACT is a multimarket partial equilibrium model that solves for global prices that equate supply and demand for every year and commodity in the model. Production is computed at the level of IMPACT's food production units, which are the intersection of regions (which are, in most cases, countries) and major water basins. IMPACT has 159 regions and 154 water basins, which combine for 320 food production units. IMPACT has 62 commodities, including 39 crops, 6 types of livestock, and 17 processed foods. IMPACT solves for annual prices for 2005 through 2050.

IMPACT uses the DSSAT crop model results for the seven crops identified above and projects those results onto crops not directly modeled using a formula found in Robinson and colleagues (2024). IMPACT uses other models as well, such as water models, that draw on the same climate input data to inform IMPACT on hydrology, water basin management, and water stress. IMPACT generates projections for population growth, GDP growth, changes in consumer demand, and productivity growth due to agricultural progress in both seed technology and farm management. These projections help IMPACT model the changes in global demand and supply that determine global prices and therefore influence what producers choose to produce and what households choose to consume. This chapter focuses on IMPACT model outputs for harvested area, yield, and production.

An earlier version of IMPACT was used to produce a three-volume study on climate impact on agriculture in Africa (Hachigonta et al. 2013; Jalloh et al. 2013; Waithaka et al. 2013).

The Major Agricultural Commodities by Region

Table 6.1 shows the major crops of Africa and each of the five subregions. Western Africa accounts for 47 percent of the cultivated area in Africa, so it dominates the totals for the continent. Because there are important differences among the regions, each is presented separately, as well. For the continent as a whole, we see that four of the top five crops (by harvested area) are cereals, with cassava being the only noncereal. The top five crops represent 45 percent of the harvested area of the region.

Maize represents almost 15 percent of the continent's harvested area, being the number one crop in all subregions except northern Africa, where it ranks eighth. In southern Africa, maize represents a third of all harvested area, though maize area has been decreasing there over the last 20 years (FAO 2022). In eastern Africa, maize represents a fifth of all harvested area, and its area has been increasing by 3.1 percent per year. Similarly, maize represents slightly more than a fifth of all harvested area in central Africa, and maize area has been increasing at a whopping rate of 4.8 percent per year. Even in western Africa, where only 11 percent of the cultivated area is dedicated to maize, the harvested area has been growing at 4.2 percent per year over the last 20 years.

For the continent overall, maize yields are small relative to those of major producers such as the United States and Brazil. Nevertheless, yield has been growing at an impressive rate of 0.9 percent per year over the last 20 years, led by eastern and southern Africa, with the growth rate for both at or above 2.0 percent per year. The combination of yield and area growth has led to a 3.6 percent per year increase in the production of maize in Africa, with western, central, and eastern Africa all growing at 5.2 percent or more per year.

Rather than discussing every major crop in Africa, we shift our attention to the major crops in Africa and its subregions that have had very fast rates of production growth over the last 20 years. The fastest rate of growth indicated in Table 6.1 is 7.8 percent per year for sesame seed in northern Africa. This includes a 4.9 percent per year growth in harvested area and a 2.8 percent per year growth in yield. Second highest is teff in eastern Africa, with production growing at a rate of 6.6 percent per year—4.4 percent yield growth and 2.2 percent area growth. Rice production is expanding rapidly in central Africa, at 6.5 percent per year, while beans are expanding rapidly in southern

TABLE 6.1—LEADING CROPS IN AFRICA AND EACH SUBREGION BASED ON HECTARES HARVESTED IN 2020, AND GROWTH RATES 2000–2020

Crop	Rank, 2020	% of all area	Harvested area (000s hectares), 2020	Yield (tons/hectare), 2020	Annualized % change, 2000–2020		
					Harvested area	Yield	Production
All of Africa							
All crops		**100.0**	**286,761**	**n.a.**	**2.3**	**n.a.**	**n.a.**
Maize	1	14.5	41,605	2.06	2.7	0.9	3.6
Sorghum	2	9.8	28,162	1.01	1.2	0.8	2.0
Cassava	3	7.7	22,011	8.64	3.6	0.1	3.7
Millet	4	7.0	20,129	0.72	0.0	0.3	0.4
Rice	5	6.0	17,281	2.11	4.2	−0.3	3.9
Northern Africa							
All crops		**100.0**	**44,524**	**n.a.**	**1.9**	**n.a.**	**n.a.**
Sorghum	1	17.1	7,614	0.7	1.9	−0.4	1.5
Wheat	2	16.0	7,123	2.67	0.3	2.0	2.3
Sesame seed	3	11.1	4,937	0.3	4.9	2.8	7.8
Olives	4	10.7	4,760	1.12	3.8	1.0	4.8
Groundnuts	5	7.5	3,333	0.95	3.9	1.2	5.2
Western Africa							
All crops		**100.0**	**134,263**	**n.a.**	**2.5**	**n.a.**	**n.a.**
Maize	1	11.0	14,704	1.72	4.2	1.1	5.3
Sorghum	2	10.5	14,121	0.96	0.8	0.4	1.2
Millet	3	10.3	13,813	0.73	−0.3	−0.1	−0.4
Cowpeas	4	9.4	12,563	0.58	1.9	2.7	4.6
Rice	5	8.4	11,335	1.84	5.0	0.5	5.6
Central Africa							
All crops		**100.0**	**32,851**	**n.a.**	**3.6**	**n.a.**	**n.a.**
Maize	1	21.1	6,930	1.07	4.8	0.5	5.3
Cassava	2	20.4	6,705	8.44	3.9	0.5	4.4
Groundnuts	3	6.8	2,246	0.98	2.6	0.8	3.4
Sorghum	4	6.4	2,090	1.08	3.2	1.5	4.7
Rice	5	5.9	1,944	1.01	6.2	0.3	6.5
Eastern Africa							
All crops		**100.0**	**50,281**	**n.a.**	**2.5**	**n.a.**	**n.a.**
Maize	1	20.2	10,169	2.36	3.1	2.0	5.2
Beans	2	8.5	4,287	0.99	2.1	2.2	4.4
Sorghum	3	7.4	3,696	1.84	1.4	3.2	4.6
Teff, etc.	4	6.4	3,218	1.80	2.2	4.4	6.6
Cassava	5	6.2	3,138	5.70	4.2	−1.9	2.3
Southern Africa							
All crops		**100.0**	**24,842**	**n.a.**	**0.8**	**n.a.**	**n.a.**
Maize	1	33.5	8,328	2.64	−0.2	2.1	1.8
Rice	2	8.0	1,997	2.25	1.6	0.8	2.4
Cassava	3	6.2	1,545	11.99	−0.4	3.3	2.9
Beans	4	5.7	1,410	0.54	7.6	−1.3	6.2
Groundnuts	5	5.4	1,346	0.59	2.2	−0.6	1.6

Source: FAO (2022).

Note: n.a. = not applicable. Values for 2020 are based on the three-year average for 2018–2020. Starting period values for 2000 are based on the three-year average for 1998–2000.

Africa. Of the major crops included in the table, millet in western Africa has seen decreasing production over the past 20 years, at a rate of 0.4 percent per year, with both area and yield trending downward.

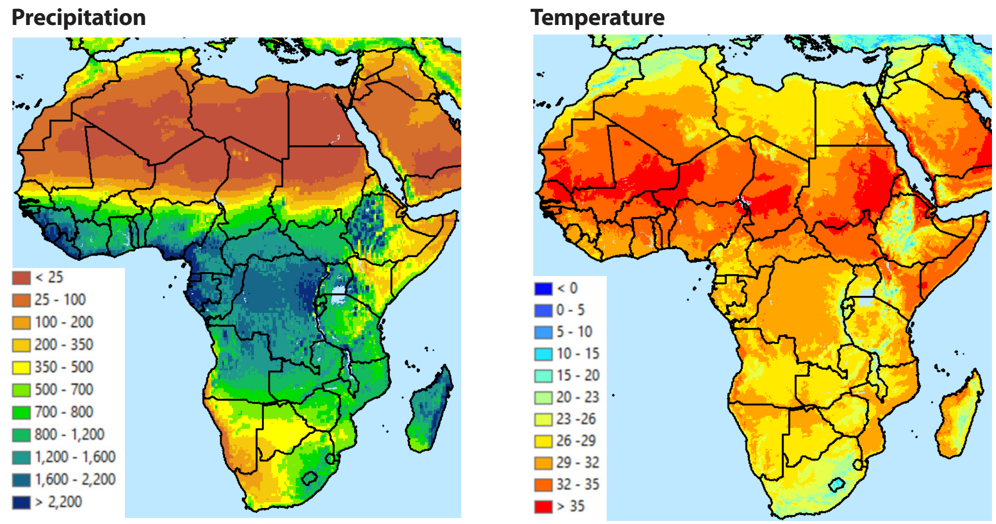
Millet in western Africa is not the only major crop showing negative yield growth in the table. It is impossible to tell from the data in the table whether any of the yield decline is attributable to climate change. The sections that follow, however, use models to help us better understand how continuing climate change will affect yields.

The Current Climate in Africa

This section focuses on the climate in Africa and the change that has already taken place. Here, we use the AgERA5 climate dataset (Boogaard et al. 2022), which is derived from the ECMWF ERA5 reanalysis. Figure 6.1 shows the annual precipitation and mean annual temperature circa 2000. The figure represents the predicted value of each based on a linear regression on the historical data from 1979 to 2021. In a very real sense, these are the climate means for 2000. We note the heterogeneity of climate in Africa, with much of northern Africa being extremely arid, along with parts of western Southern Africa and the eastern half of eastern Africa. We also note areas of high rainfall, mostly along certain coastlines and in mountainous regions. In terms of temperature, the Sahel is much warmer than the rest of the continent. Cooler areas exist in the highlands and along parts of the Mediterranean coast.

Figure 6.2 shows that climate change is already taking place and has shifted rainfall and temperature patterns in much of the continent. The maps are produced from regressions at each pixel in the AgERA5 dataset (Boogaard et al. 2022). White areas mean that the trend was not statistically significant at the 10 percent level. Figure 6.2 also shows that much of the central part of the continent has experienced a significant drying trend over the 43-year period in the dataset. In addition, a few areas in southern Africa and Angola in central Africa are notably wetter. Most of

FIGURE 6.1—ANNUAL PRECIPITATION (MM) AND MEAN ANNUAL TEMPERATURE (°C), CIRCA 2000



Source: Boogaard et al. (2022). Note: Averages for 1985 to 2015.

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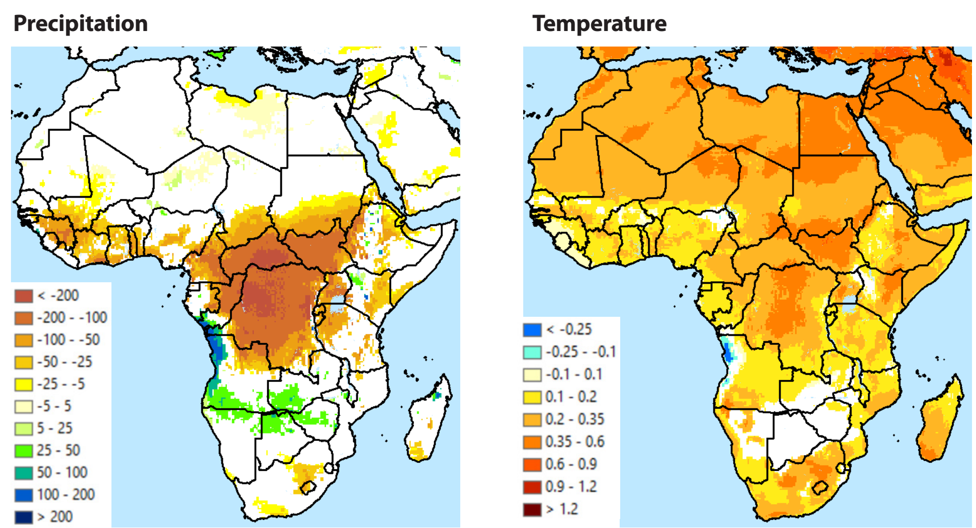
FIGURE 6.2—PRECIPITATION CHANGE (MM) AND TEMPERATURE CHANGE (°C) PER DECADE, 1979–2021



Source: Boogaard et al. (2022). Note: The figure shows only changes with a 90% confidence interval based on regression parameter estimates and their standard errors. To determine annual change, the legend can be divided by 10, and for the entire 43-year period, it can be multiplied by 4.3.

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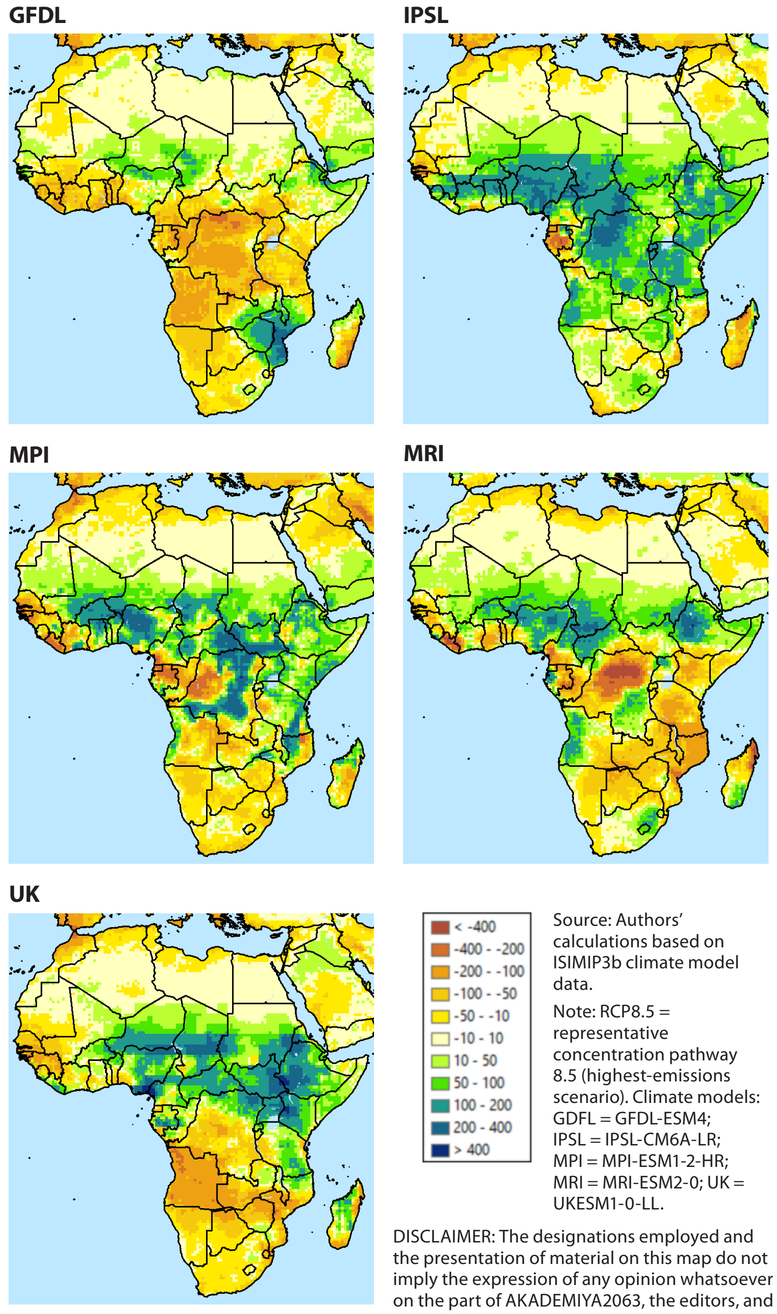
FIGURE 6.3—PROJECTED CHANGE IN ANNUAL PRECIPITATION (MM), 2020–2050, RCP8.5



Source: Authors' calculations based on ISIMIP3b climate model data.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). Climate models: GDFL = GFDL-ESM4; IPSL = IPSL-CM6A-LR; MPI = MPI-ESM1-2-HR; MRI = MRI-ESM2-0; UK = UKESM1-0-LL.

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the continent has experienced statistically significant increases in temperature, with the highest concentrated in northern and central Africa.

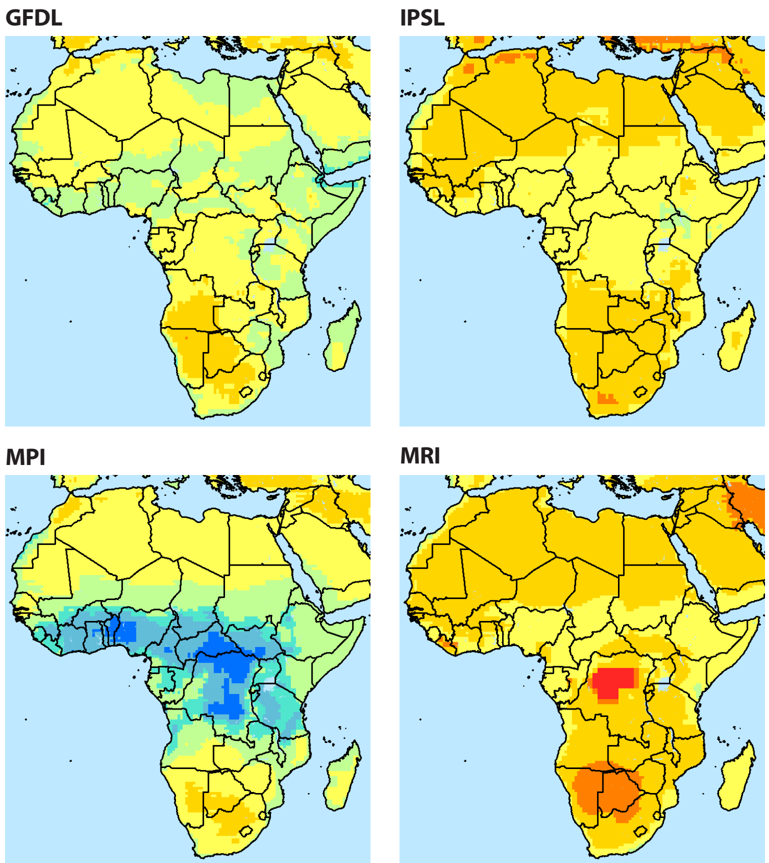
Projected Changes in Climate for Africa

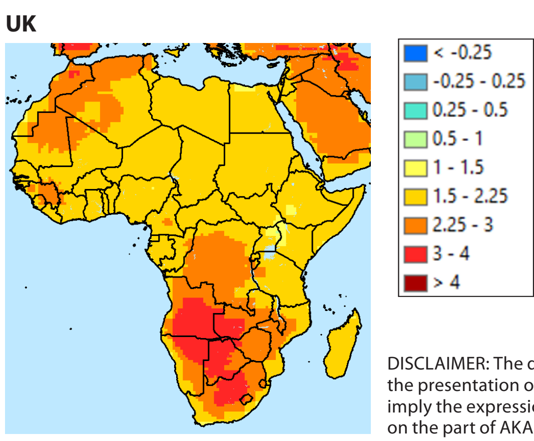
Figure 6.3 shows the annual precipitation changes from 2020 to 2050 for the five climate models used throughout this chapter for the RCP8.5 scenario. As can be easily seen, the models are not in total agreement about the direction and magnitude of change in precipitation. Generally, southern Africa is projected to become drier, though this is less clear for Malawi, Mozambique, Zambia, and Zimbabwe. Much of eastern Africa, particularly Ethiopia, is projected to become wetter. In fact, in all the models, there is a band of rainfall increase that extends westward from Ethiopia to Mali or beyond. Rainfall projections for central Africa differ across models. One of the main points for the reader to understand is that there is considerable uncertainty about the direction and magnitude of change. Therefore, donors, policymakers, researchers, and farmers need to be careful not to make policies, plans, and investments that will be successful only if a particular future climate scenario becomes reality. Models that account for climate uncertainty can be used to assess alternative future scenarios and inform the decision-making process.

Furthermore, in addition to uncertainty about the direction and magnitude of average precipitation change, much has been written about increasing variability, of rainfall in particular, under climate change, and the possibility that rainfall events will become more intense, with more precipitation falling in a shorter amount of time. The climate and economic modeling results presented in this chapter do not reflect the potential for increasing variability, in part because they focus on average results for each climate model, but also because most climate models do not project large increases in variability.

Figure 6.4 shows the ranges of temperature change projected for the five climate models in this study. The IPSL projections show the least change in temperature, particularly in the middle latitudes. In fact, all the models, except possibly the UK model, project the least temperature change near the equator, though much of this zone of low temperature increase is located from the equator northward to 15 to 20 degrees north latitude. The UK climate model shows the greatest changes in temperature, with southern Africa having the greatest increase on the continent, particularly in Angola (which is classified as part of central Africa in this chapter), Botswana, Namibia, and South Africa. Since the UK model also projects a drier southern Africa, this means that the UK climate model projects the greatest negative impact on agriculture. The MRI model shows the second-greatest increase in temperature, with part of the Democratic

FIGURE 6.4—PROJECTED CHANGE IN MEAN DAILY MAXIMUM TEMPERATURE (°C), 2020–2050, RCP8.5





Source: Authors' calculations based on ISIMIP3b climate model data.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). Climate models: GDFL = GFDL-ESM4; IPSL = IPSL-CM6A-LR; MPI = MPI-ESM1-2-HR; MRI = MRI-ESM2-0; UK = UKESM1-0-LL.

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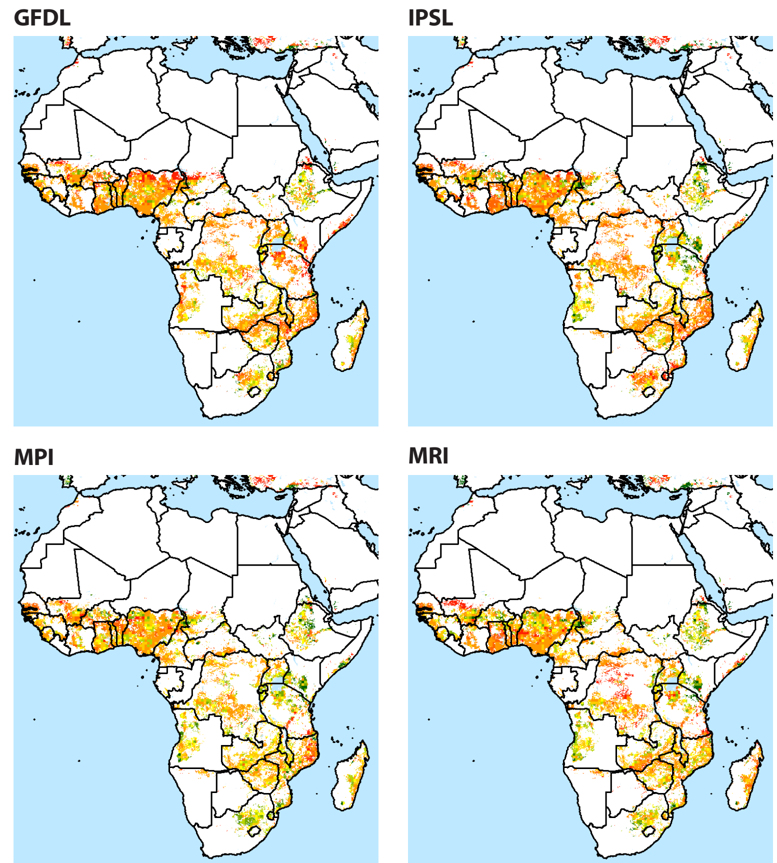
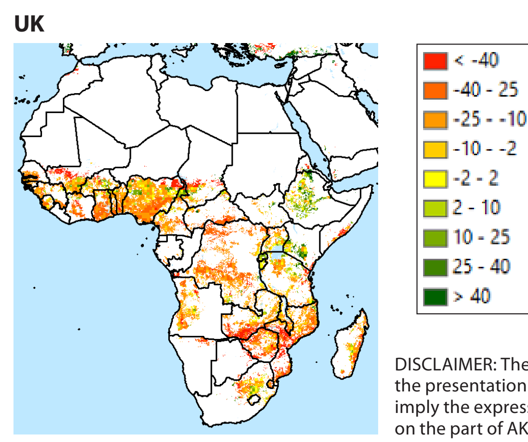
FIGURE 6.5—PERCENTAGE CHANGE IN RAINFED MAIZE YIELDS DUE TO CLIMATE CHANGE, 2005–2050, RCP8.5





Source: DSSAT crop model results based on five RCP8.5 climate models from ISIMIP3b.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). Climate models: GDFL = GFDL-ESM4; IPSL = IPSL-CM6A-LR; MPI = MPI-ESM1-2-HR; MRI = MRI-ESM2-0; UK = UKESM1-0-LL.

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Republic of the Congo warming more than the rest of the continent.

Direct Impact of Climate Change on Yields

This section presents yield computations from the DSSAT crop model for seven key crops, based on the climates of 2005 (baseline) and 2050. This analysis was performed separately for rainfed and irrigated crops. Space does not allow the presentation of maps for all the crops, but Figure 6.5 shows the location-specific changes in rainfed maize yields as a result of the climate change projected by each climate model, assuming farm management practices do not change over time. In South Africa, some of the climate models suggest that maize yields will improve, while in other models, such as the very hot UK model, they are projected to decline. However, Nigeria, for example, shows yield decreases in much of its area in every climate model. This is because the growing season in most parts of South Africa is cooler than in Nigeria; thus, additional heat in South Africa could push the temperature closer to the optimal temperature for maize, whereas the temperature in Nigeria appears to already be above the ideal for maize, so with climate change making it hotter still, yields decline.

With the equator passing through eastern Africa, one would assume that temperatures there are already higher than the optimal for growing maize. But much of the maize in eastern Africa is grown in the highlands, where the elevation keeps the temperature cooler. Hence a modest temperature increase raises yields. Increased rainfall in eastern Africa also contributes to the higher yields projected in much of the region.

TABLE 6.2 —PERCENTAGE CHANGE IN RAINFED YIELDS DUE TO CLIMATE CHANGE, 2005–2050, RCP8.5

Country/ region	Median	Range		Includes CO_2
		Min	Max	
Groundnuts				
World	**9.3**	6.1	15.0	20.2
Africa	**6.8**	−3.6	8.8	20.9
Eastern Africa	**12.4**	−11.0	15.8	21.0
Central Africa	**9.3**	2.7	14.3	22.4
Northern Africa	**4.1**	−23.4	37.7	22.1
Southern Africa	**5.3**	−9.4	15.0	18.8
Western Africa	**3.0**	−5.7	8.0	20.5
Maize				
World	**−12.5**	−36.2	−8.1	3.8
Africa	**−11.0**	−14.8	−5.6	−0.1
Eastern Africa	**−3.0**	−17.1	2.2	−0.2
Central Africa	**−11.3**	−18.9	−7.6	−0.2
Northern Africa	**−26.4**	−38.5	−7.8	0.0
Southern Africa	**-9.4**	−18.0	−1.4	−0.1
Western Africa	**−17.7**	−18.8	−13.0	−0.2
Potatoes				
World	**0.9**	−14.0	11.0	17.0
Africa	**−16.4**	−32.4	−3.4	12.0
Eastern Africa	**−6.0**	−19.0	1.0	11.8
Central Africa	**−29.8**	−59.2	0.3	8.3
Northern Africa	**11.0**	−17.2	31.9	29.0
Southern Africa	**−28.0**	−51.5	−6.6	13.3
Western Africa	**−57.0**	−81.4	−32.9	5.4
Rice				
World	**8.2**	3.7	14.7	15.0
Africa	**2.9**	−4.4	4.0	11.0
Eastern Africa	**−4.5**	−18.8	10.0	9.6
Central Africa	**2.0**	−7.0	3.6	11.2
Northern Africa	**29.5**	6.7	52.9	15.4
Southern Africa	**6.6**	1.3	12.5	8.8
Western Africa	**3.4**	−3.3	5.8	12.1
Sorghum				
World	**−2.4**	−5.9	−0.2	2.2
Africa	**−1.1**	−13.2	0.6	1.2
Eastern Africa	**9.3**	−7.9	11.2	0.8
Central Africa	**−0.8**	−5.8	3.8	0.8
Northern Africa	**5.7**	−23.2	8.8	1.8
Southern Africa	**2.9**	−7.4	4.6	0.9
Western Africa	**−5.2**	−11.8	−1.8	0.8
Soybeans				
World	**6.9**	−1.7	19.1	22.1
Africa	**13.0**	8.7	16.4	22.6
Eastern Africa	**21.9**	2.5	34.3	26.5
Central Africa	**12.6**	8.5	16.8	23.5
Northern Africa	**28.7**	20.8	62.6	22.1
Southern Africa	**11.0**	0.3	27.5	21.2
Western Africa	**12.2**	4.1	17.9	22.4
Wheat				
World	**21.1**	17.1	24.3	14.4
Africa	**−31.3**	−37.0	−22.0	6.9
Eastern Africa	**1.1**	-1.0	3.1	12.8
Central Africa	**−5.0**	−11.3	3.1	11.6
Northern Africa	**−42.5**	−50.9	−31.7	4.9
Southern Africa	**−4.9**	−22.6	1.6	10.7
Western Africa	**−21.2**	−34.2	48.0	8.5

Source: DSSAT crop model results based on five RCP8.5 climate models from ISIMIP3b.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). The model assumes no adaptation measures such as changing crop mixes or cultivars in any given location. It also assumes no land expansion.

Table 6.2 summarizes the findings of the crop modeling analysis for the seven rainfed crops, aggregated to the continent and the five subregions. The main findings are in the "Median" column, which represents the median value across the five climate models used. These results include CO_2 fertilization. The range across the five models is given by the "Min" and "Max" columns. To obtain a measure for climate change that excludes CO_2 fertilization, the value in the "Includes CO_2" column can be subtracted from the "Median" column.

Beginning again with rainfed maize, let us look at the tabulated results presented in Table 6.2. In Africa as a whole, climate change is projected to reduce rainfed maize yields by 11 percent at the median. But this suggests that Africa may have a very slight comparative advantage with regard to maize and climate change, since the world as a whole is projected to experience a more than

12 percent yield reduction. If the most negative climate model proves to be correct, Africa will have a major comparative advantage vis-à-vis the rest of the world, with a 15 percent yield reduction for Africa compared to a 36 percent yield reduction for the whole world. We also see that the world's yield would be reduced by an additional 4 percent without CO_2 fertilization, while almost no CO_2 fertilization effect is projected for Africa.

With sorghum, the story is similar, though the magnitude of the yield reduction due to climate change is roughly 10 percentage points less for sorghum. At the median, Africa is projected to lose 1 percent, while the world as a whole is projected to lose more than 2 percent. However, in the most negative climate model, Africa is projected to see a greater reduction than the rest of the world.

Climate change (with the CO_2 fertilization effect) is projected to have a positive impact on rice, soybean, and groundnut yields in Africa—with a CO_2 boost of 11, 23, and 21 percent, respectively. Of the three crops, only soybeans represent a comparative advantage for Africa compared to the rest of the world—though currently soybeans are cultivated only in relatively small areas in Africa. Potatoes and wheat in Africa, however, are projected to experience large yield losses due to climate change, with wheat in particular seeing a 52 percentage point difference compared to the whole world (a 31 percent loss for Africa and a 21 percent gain for the world). Northern Africa is projected to see a more than 42 percent reduction in rainfed wheat yields (the decrease is much less for irrigated yields—only 5 percent—but roughly two-thirds of wheat grown in northern Africa is rainfed). Eastern Africa is actually projected to receive a small boost in wheat yields from climate change—though still a 20 percentage point lower boost relative to the whole world.

Table 6.3 shows the impact of climate change on irrigated crops, based on projections using the DSSAT crop model. Northern Africa appears to have half of the continent's irrigated crops (measured by harvested area). Roughly a third of the harvested area in northern Africa is irrigated. Southern Africa, with 18 percent irrigated, is the only other subregion with more than 6 percent of harvested area irrigated. Apart from wheat, irrigated crops in Africa have roughly the same or better yield projections than the rest of the world. For wheat, Africa is projected to have yields that are more than 4 percent lower, while the world is projected to have yields that are 8 percent higher.

While the concept of comparative advantage arising from climate change gives some idea of how agriculture may change in Africa, the IMPACT model more fully incorporates not only climate change but also productivity changes due to investment in new crops, fertilizer, and agricultural extension, as well as changes in global demand, to indicate how African agriculture will likely evolve by 2050. Those results are presented in the following section.

TABLE 6.3—PERCENT CHANGE IN IRRIGATED YIELDS DUE TO CLIMATE CHANGE, 2005–2050, RCP8.5

Country/ region	Median	Range		Includes CO_2
		Min	Max	
Groundnuts				
World	**5.6**	−6.8	10.6	17.1
Africa	**2.3**	−8.7	11.6	19.5
Northern Africa	**1.4**	−9.9	11.5	19.7
Southern Africa	**10.2**	−1.0	15.2	17.9
Maize				
World	**−18.9**	−29.8	−12.6	1.8
Africa	**−5.5**	−9.5	−1.4	0.8
Eastern Africa	**−14.7**	−24.0	−11.0	2.0
Central Africa	**−18.7**	−29.2	−13.9	2.6
Northern Africa	**−1.5**	−5.2	3.5	0.0
Southern Africa	**−9.8**	−11.7	−6.6	1.5
Western Africa	**−26.4**	−37.7	−18.2	2.5
Potatoes				
World	**8.0**	−1.0	12.3	18.2
Africa	**26.2**	21.0	27.4	33.9
Northern Africa	**28.5**	23.7	30.8	34.6
Western Africa	**<−50**	<−50	−9.9	1.5
Rice				
World	**7.8**	4.9	9.6	14.2
Africa	**5.4**	1.2	6.3	10.9
Eastern Africa	**3.1**	1.4	4.4	12.1
Central Africa	**7.0**	1.9	11.7	17.4
Northern Africa	**4.8**	−7.3	6.0	19.7
Southern Africa	**6.5**	5.7	8.7	7.9
Western Africa	**2.0**	−7.8	6.4	14.4
Sorghum				
World	**−2.7**	−5.7	3.1	0.4
Africa	**−3.0**	−5.7	−2.3	1.0
Eastern Africa	**−7.4**	−13.6	−4.4	0.3
Northern Africa	**−3.2**	−4.9	−1.7	0.9
Western Africa	**0.8**	−7.1	2.9	0.9
Wheat				
World	**8.0**	6.4	10.4	8.4
Africa	**−4.5**	−10.1	0.9	9.6
Northern Africa	**−5.4**	−10.2	0.6	9.3
Southern Africa	**0.6**	−7.4	2.6	10.1
Western Africa	**−6.9**	−33.1	5.3	12.1
Soybeans				
World	**6.5**	−13.2	10.4	16.6
Africa	**14.2**	10.0	14.9	17.3
Southern Africa	**14.2**	10.0	14.9	17.3

Source: DSSAT crop model results based on five RCP8.5 climate models from ISIMIP3b.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). Regions were omitted if they have less than 5,000 hectares of the crop according to SPAM 2005v3.1 (You et al. 2014).

Projections for African Agriculture

IMPACT is a multimarket partial equilibrium model of global food and agriculture that was first developed in the mid-1990s (Robinson et al. 2024; Rosegrant et al. 2024). It is used to run scenarios projecting changes in supply and demand for 159 countries and 62 agricultural commodities into the future—currently up to 2050. It integrates economic, climate, water, and crop models. The IMPACT model takes into account changes in global demand (driven primarily by changes in population, income, and consumer tastes) and changes in global supply (driven by assumptions about growth in cropland and improvements in agricultural production technology), and solves for the global price of each commodity that equalizes global supply and demand. As part of this process of equalizing global quantities supplied and demanded, farmers decide whether to increase or decrease the amount of land allocated to each crop based on profitability and comparative advantage. They also make decisions about how intensively to manage each crop, which affects yields.

This section reports on IMPACT model projections that rely on the climate models previously discussed in this chapter and the crop model results presented in the preceding section. Table 6.4 summarizes key IMPACT model projections for the continent for the 10 leading crops by area harvested, under the high-emissions scenario (RCP8.5) and the middle-of-the-road economic scenario (SSP2). Table 6.5 does the same thing for the top five crops for each subregion. Similar to Tables 6.2 and 6.3, these tables report the median change along with the range across the five climate models. But it is important to understand that the median and range include projected changes in productivity levels as well as the climate and CO_2 fertilization effects. To break these down further, the "Clim" column reports the climate effect (ignoring CO_2 fertilization), and the "CO_2" column reports the CO_2 fertilization effect. So, the productivity growth effect without the climate and CO_2 effects is the "Median" minus the sum of "Clim" and "CO_2." For example, the pure productivity growth effect for maize yield is 23.4 minus –2.9 (that is, –3.4 plus 0.5), which is approximately 26.3 percent.

TABLE 6.4 —PROJECTED CHANGES IN PRODUCTION FOR THE TOP 10 CROPS FOR AFRICA, 2020–2050, RCP8.5

Crop	Cultivated area, 2020 (000s hectares)	Percentage change in yield, 2020–2050					Percentage change in harvested area, 2020–2050					Percentage change in production, 2020–2050				
			Range		Includes			Range		Includes			Range		Includes	
		Median	Min	Max	Clim	CO_2	Median	Min	Max	Clim	CO_2	Median	Min	Max	Clim	CO_2
Maize	39,721	23.4	21.9	26.6	–3.4	0.5	18.6	15.5	22.0	5.8	2.1	49.1	40.7	52.4	4.7	2.1
Sorghum	28,009	45.6	44.3	46.6	–0.5	0.0	44.3	44.0	45.6	0.6	1.3	110.8	108.1	111.9	0.7	1.1
Cassava	21,272	22.8	22.0	25.5	0.4	–0.5	24.1	23.1	24.7	–0.7	1.1	52.5	51.1	54.5	–0.3	0.7
Millet	20,429	60.6	53.1	68.5	5.3	0.0	33.3	31.4	33.8	–2.3	0.5	113.9	101.1	121.6	2.9	0.5
Rice	17,124	40.6	38.0	46.4	–6.9	5.9	8.2	6.9	10.8	–0.8	–5.0	52.2	47.6	62.3	–7.5	0.7
Groundnuts	17,039	17.5	13.5	21.4	–9.1	8.7	33.8	31.6	39.4	5.5	–7.1	59.0	56.9	60.1	–3.2	2.3
Cowpeas	14,238	69.2	60.9	71.1	1.0	2.2	33.4	33.1	36.8	–0.7	–0.7	125.7	120.3	127.7	0.3	1.4
Wheat	9,912	37.7	36.3	41.8	–11.0	5.2	1.2	0.1	3.4	–5.7	0.2	39.6	36.5	46.5	–16.0	5.2
Beans	9,736	44.5	39.3	46.3	1.5	4.3	40.7	40.3	43.7	1.2	–3.3	104.2	95.4	109.7	3.1	1.0
Vegetables	9,474	43.8	39.9	50.6	–10.1	5.6	31.4	29.4	32.7	–3.7	–1.2	87.7	81.3	99.2	–13.9	4.1

Source: Rosegrant et al. (2024).

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). The model assumes CO_2 fertilization. Median results are from five global climate models. "Clim" compares the counterfactual results if the climate did not change beyond 2020 to scenarios with climate change but no CO_2 fertilization (the climate-only effect). "CO_2" is the change when CO_2 fertilization is taken into account.

As mentioned in the opening to this section of the chapter, the reader should keep in mind that every number in every column accounts for substitution effects from the changes in global supply and demand that determine global prices. So, while the CO_2 effect for groundnuts in Africa in Table 6.2 is 21 percent, in Table 6.4 it is under 9 percent. This reflects the expectation that worldwide, with CO_2 fertilization, global production will be boosted, which would drive prices down and disincentivize farmers from taking additional steps to increase productivity.

Table 6.4 also differs from Tables 6.2 and 6.3 in that it includes projected changes to harvest area and production. Table 6.2 shows that Africa would have a strong comparative disadvantage in growing wheat in the future due to climate change. As a result, we see in Table 6.4 that of the 10 crops presented, area growth is by far the smallest for wheat, with an increase of just 1 percent. Even with a very respectable 38 percent projected growth in yield between 2020 and 2050, wheat is also projected to have the smallest increase in total production among the top 10 crops, with an increase of slightly less than 40 percent.

This is not very much less than the projected production increase for maize, at 49 percent. But the change in maize production was more balanced, with a 19 percent increase in harvested area and a 23 percent increase in yield. Cereals that might be considered maize substitutes—sorghum and millet—are projected to have a total production increase more than twice as fast as maize, with sorghum production increasing by almost 111 percent and millet production increasing by 114 percent.

Millet yields will increase faster than sorghum yields between 2020 and 2050, with a growth rate of 61 percent (the second-highest rate of growth among the top 10 crops) compared to 46 percent. At the same time, however, sorghum area will grow faster than millet area, at a rate of 44 percent (the highest among the top 10 crops) compared to 33 percent.

The only other cereal in the top 10 crops for Africa is rice. Its area growth is projected to be the second slowest among the top 10 crops, at 8 percent, ahead of only wheat. However, rice yields are projected to grow by 41 percent, leading to a 52 percent total production growth.

The crop projected to have the greatest increase in production is cowpeas, with a 126 percent increase driven by a 69 percent growth in yields—the highest among the top 10 crops—and a 33 percent increase in harvested area. The other legume in the table—beans—is also projected to see significant growth in production, at 104 percent, driven by yield growth of nearly 45 percent and area growth of 41 percent (the second-highest area growth, behind only sorghum).

Table 6.5 shows subregional production projections. In eastern Africa, we see sorghum production projected to grow by 168 percent between 2020 and 2050, driven by a 72 percent increase in harvested area and a 56 percent boost in yields. Similarly, central Africa is projected to have a large increase in the production of sorghum, with 132 percent growth, due to a 59 percent increase in area and a 46 percent increase in yields. Sorghum will also see the most rapid expansion of area among the top five crops in northern Africa and western Africa.

In southern Africa, production of rice is projected to increase by 139 percent, driven by a 93 percent increase in yields (though almost none of this is climate related). Bean production in southern Africa is similarly projected to grow by 135 percent, with the growth split between a 56 percent yield increase and a 51 percent area increase. In western Africa, cowpea production is projected to expand by 121 percent, led by a 68 percent yield increase.

Finally, it is important to note the 29 percent decline in barley production in northern Africa, reflecting a 14 percent decline in yield and an 18 percent decline in harvested area.

Focusing on the "Clim" and "CO_2" columns, we see that northern Africa experiences the greatest yield shocks from climate change, which in some cases translates into significant reductions in harvested area as well, resulting in fairly large production shocks for barley and wheat in northern Africa. Teff is projected to have a 10 percent production shock in eastern Africa, and rice has a 9 percent production shock in western Africa (though only 6 percent with the CO_2 fertilization effect).

Generally, the impact of climate change on crops in an average year and in the aggregate seems relatively modest in Africa, according to the IMPACT model results presented in Table 6.5. Some yield gains are projected from climate change and, of course, also some declines. What is not accounted for in the model are the national and subnational shocks, which are averaged out at the continent and subregion levels and therefore will be more extreme. Above, Figure 6.5 is cited as an example of the spatially differentiated impact of climate change on yields—how it creates "hot spots," or areas of high average losses, while also creating spots of opportunity, where yields increase as a result of climate change. Hot spots are part of the reason that climate change can be

TABLE 6.5 —PROJECTED CHANGES IN PRODUCTION FOR THE TOP 5 CROPS FOR EACH AFRICAN SUBREGION, 2020–2050, RCP8.5

Crop	Cultivated area, 2020 (000s hectares)	Percentage change in yield, 2020–2050					Percentage change in harvested area, 2020–2050					Percentage change in production, 2020–2050				
			Range		Includes			Range		Includes			Range		Includes	
		Median	Min	Max	Clim	CO_2	Median	Min	Max	Clim	CO_2	Median	Min	Max	Clim	CO_2
Eastern Africa																
Maize	10,053	35.5	30.1	39.4	0.2	0.6	15.1	13.3	18.9	4.4	2.0	56.0	47.5	65.9	4.6	2.6
Beans	5,006	43.4	34.6	45.7	2.8	6.6	33.1	31.6	37.0	1.4	–2.6	91.4	77.8	99.4	4.4	4.0
Sorghum	3,759	56.1	55.5	57.2	1.8	–0.9	71.8	70.8	72.5	1.7	1.2	168.2	165.9	170.0	3.4	0.4
Teff, etc.	3,282	50.9	47.7	57.7	–4.6	3.0	13.2	12.6	14.3	–6.1	–1.8	70.2	66.4	79.5	–10.4	0.7
Cassava	3,021	51.3	47.2	53.2	–0.1	–0.4	23.0	21.6	23.6	–0.5	0.8	86.1	82.0	87.8	–0.6	0.4
Central Africa																
Maize	7,011	31.6	19.8	33.4	–7.6	1.3	24.0	21.5	25.5	2.7	1.1	61.3	49.8	65.5	–6.1	2.2
Cassava	6,660	30.3	26.3	32.6	0.2	–0.2	24.9	24.0	25.5	–0.4	0.7	62.5	57.8	65.9	–0.5	0.6
Groundnuts	2,315	23.8	21.1	24.9	–1.2	4.4	43.5	40.8	50.4	5.3	–6.3	76.7	73.7	86.1	3.4	–1.8
Sorghum	2,063	46.0	43.5	50.4	–3.6	0.3	58.8	58.2	60.2	0.8	0.8	132.1	127.6	139.4	–2.8	1.2
Rice	2,003	34.6	24.2	38.4	–6.7	7.7	13.7	9.3	16.3	–0.1	–5.9	53.1	35.6	60.4	–6.8	1.8
Northern Africa																
Sorghum	7,312	26.5	23.9	28.3	–1.0	0.4	39.7	38.8	41.4	0.8	1.5	76.5	73.0	81.4	–0.5	2.0
Wheat	7,244	25.1	22.4	30.4	–13.5	4.3	–9.5	–10.2	–7.2	–5.8	–0.1	14.0	9.7	21.0	–18.7	4.7
Other oilseeds	3,919	21.1	17.9	25.6	–7.7	2.8	27.7	25.3	29.6	6.8	–5.1	54.9	52.9	57.7	–0.8	–2.3
Rapeseed	3,516	4.0	3.4	5.6	–0.6	–3.0	5.9	4.9	6.4	–1.3	–4.0	9.9	8.4	12.4	–2.0	–6.9
Vegetables	3,441	–13.7	–15.8	–11.0	–11.3	1.6	–17.8	–18.0	–16.7	–6.2	–2.1	–29.1	–30.8	–26.8	–16.8	–0.5
Southern Africa																
Maize	7,949	18.8	17.2	29.9	–7.6	0.4	16.5	13.8	19.4	4.5	2.6	40.0	35.1	54.2	–1.9	2.4
Rice	1,716	92.9	91.0	96.7	0.5	1.2	24.4	23.6	26.5	0.3	–4.9	139.2	138.0	148.9	0.6	–3.9
Cassava	1,524	38.6	35.8	44.2	–0.3	–1.0	18.2	17.0	19.4	–1.5	1.4	63.3	59.3	70.4	–2.0	0.3
Groundnuts	1,479	22.1	21.5	22.6	–3.4	5.9	32.2	27.5	37.3	7.0	–8.7	60.7	56.4	67.6	2.7	–2.4
Beans	1,438	55.9	45.4	63.6	0.2	–0.9	51.3	47.7	55.8	–1.2	–4.1	134.7	114.7	155.1	–1.0	–5.4
Western Africa																
Sorghum	14,254	39.4	35.9	40.4	–0.7	0.3	37.0	36.4	38.6	0.2	1.3	90.6	85.3	93.1	–0.6	1.5
Millet	14,016	51.2	49.0	59.7	3.9	0.2	27.9	27.3	29.4	–2.6	0.4	94.5	90.7	103.2	1.7	0.7
Maize	13,499	12.5	8.4	16.8	–3.8	0.5	18.1	13.5	22.4	8.9	2.6	32.8	28.0	37.9	5.6	2.2
Cowpeas	12,732	68.3	58.6	70.1	1.7	2.0	31.5	31.2	34.0	–0.6	–0.7	121.3	112.4	123.2	1.0	1.3
Rice	11,567	39.6	36.1	44.3	–7.7	6.8	6.8	5.3	8.7	–1.1	–4.5	49.1	43.2	56.3	–9.0	2.6

Source: Rosegrant et al. (2024).

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). The model assumes CO_2 fertilization. Median results are from five global climate models. "Clim" compares the counterfactual results if climate did not change beyond 2020 to scenarios with climate change but no CO_2 fertilization (the climate-only effect). "CO_2" is the change when CO_2 fertilization is taken into account. "Other oilseeds" include sesame and safflower. Oilseeds that are already accounted for are groundnuts, soybeans, sunflowers, rapeseed, and oil palm.

very harmful to farmers, agriculture, food security, and livelihoods, even when averages at the national level do not indicate reasons for alarm.

Low-yield Events Arising from Extreme Climate Events

What is also not accounted for in this analysis are the yield shocks associated with droughts, floods, and heat waves, along with other climate impacts that occur during extremely adverse years. Thomas and colleagues (2022) examine the incidence of low-yield events for maize in 10 countries in southern Africa. One of their findings is that under the highest-emissions scenario—similar to the RCP8.5 scenario used in this chapter—the frequency of what is currently a 1-in-20-year low-yield event will occur every 3.5 years by the 2060s. This result is driven by the change in the mean temperature and precipitation and by uncertainty about the future. If variability of precipitation were to increase, as some climate models suggest, then low-yield events would occur even more frequently.

Thomas and colleagues (2022) were also able to compute changes in the frequency of low-yield events at the pixel level to produce a map similar to the one in Figure 6.5 in this chapter. Such a map can help policymakers identify high-risk areas and guide them in creating strategies and investments to lower the risk to farmers in those locations.

Future Areas of Research

In addition to expanding the study of the consequences of increased precipitation variability, subject areas that deserve additional research include the impact of heat on agricultural labor productivity and the impact of heat and drought stress on the productivity, morbidity, and mortality of livestock and fisheries. One of the greatest challenges in modeling these issues is determining how much adaptation can take place. For example, heat stress on laborers could lead to substituting labor with more mechanical devices such as tractors. Nelson and colleagues (2024) endeavor to account for forms of adaptation to heat stress on labor and livestock through, for example, measures such as providing shade or fans for cooling.

Concluding Remarks

Table 6.2 showed that with climate change, some crops—including maize, sorghum, and soybeans—will see either a greater production boost or a lower loss in Africa than in the rest of the world. Groundnuts and rice will do modestly worse than in the rest of the world, but wheat and potatoes will suffer large losses that are much greater than those seen in the world as a whole.

The impact of climate change, however, is not uniform throughout Africa. Northern Africa appears likely to fare worse than the rest of the continent because of the importance of wheat and barley in its current agriculture system; these crops are projected to experience large declines due to climate change, while for the rest of the world, yields of wheat and barley will rise due to climate change. Eastern Africa, despite being on the equator, will possibly fare best among all the subregions under climate change, in large part due to the higher elevation at which most of its cropping takes place, which keeps temperatures cool.

Climate change is not uniform within subregions or within countries either. We saw in Figure 6.5 how the same country can experience yield improvements from climate change in some locations along with large declines in other locations.

In addition to spatial heterogeneity creating hot spots with climate change, temporal heterogeneity—interannual variability of the weather—deserves more research because the shocks, or bad years, are the ones that cause the greatest threat to food security. More consideration should be given not only to reducing risk for farmers but also to smoothing prices and food availability for consumers. Establishing strategic reserves is one way to do this, but it is not the only way.

One large area of uncertainty is related to the issue of CO_2 fertilization (US Department of Energy 2020). Experts make passionate arguments for and against including the effect in modeling (Allen et al. 2020; Li et al. 2017; Toreti et al. 2020; Zhu et al. 2023). For some crops, including the effect can result in projected yields that are 20 to 25 percentage points higher over a 30-year time span. The decision to include or exclude the effect creates much uncertainty in the model. However, the CO_2 fertilization effect is significantly reduced in the context of the global economic model in which substitution takes place as prices rise or fall based on production.

As we saw in Figures 6.3 and 6.4, there are large differences among climate models, including a wide range in the projected temperature change (from little warming to much hotter) and precipitation (some predict a drier future, and some predict a wetter future). Policymakers cannot make policies based on just one selected climate model, because they may be very wrong. The best policies and investments are those that give farmers multiple options for adaptation, reduce risk, or increase productivity over a wide range of climate outcomes. Models such as DSSAT and IMPACT, which are used in this study, can be used to run scenarios to guide decisions by policymakers.

As a whole, climate-related risk to agriculture in Africa is modest in an average year. But climate change will increase production risk, and some areas and some crops are at much greater risk. Strategies should focus on reducing risk, especially in areas where the risk is known to be high. Plans should incorporate important components such as agricultural research to develop new varieties and techniques; information services to help farmers adapt more quickly; and risk-reducing approaches such as irrigation, mechanization, and agroforestry.

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The author accepts responsibility for any errors that appear in this paper.