CHAPTER 2

The Effects of Climate Change on Agriculture and Food Security in Africa

Keith Wiebe, Timothy B. Sulser, Daniel Mason-D'Croz, and Mark W. Rosegrant[1]

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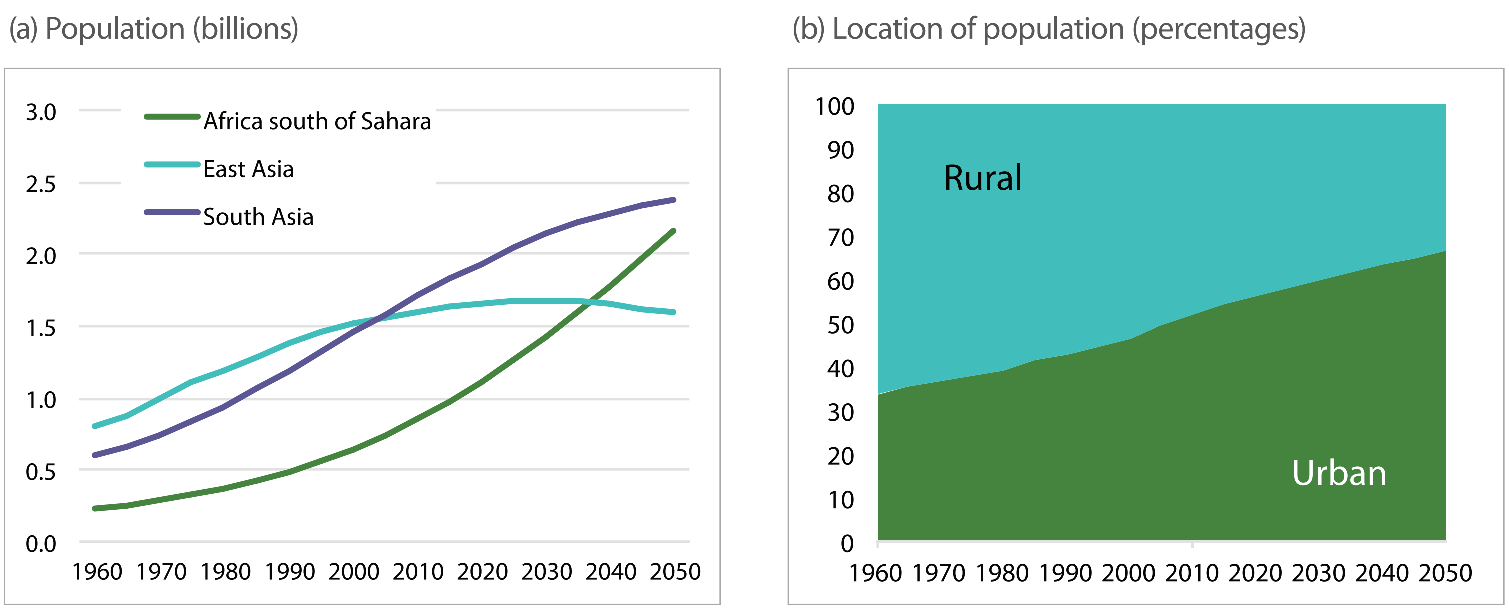
Climate change will play an increasingly important role in Africa, as elsewhere, during the course of the 21st century. Rising temperatures and increased frequency of extremely dry and wet years are expected to slow progress toward increased productivity of crop and livestock systems and improved food security, particularly in Africa south of the Sahara (FAO 2016). But other drivers of change in agriculture and food security are also changing in significant ways. In order to place the impacts of climate change in context, we look first at changes that affect demand for food and other agricultural commodities, and then at changes affecting supply.

Key Trends and Challenges for Agriculture and Food Security in Africa

Demand Side: Population, Income, Urbanization, and Globalization

On the demand side, a key factor that immediately distinguishes Africa from other regions of the world is population (Figure 2.1, panel [a]). The populations of East Asia and South Asia are projected to peak and then begin declining by the 2030s and 2050s, respectively, whereas the United Nations

FIGURE 2.1—CHANGES IN DEMOGRAPHICS WILL INFLUENCE THE LEVEL AND NATURE OF DEMAND FOR FOOD



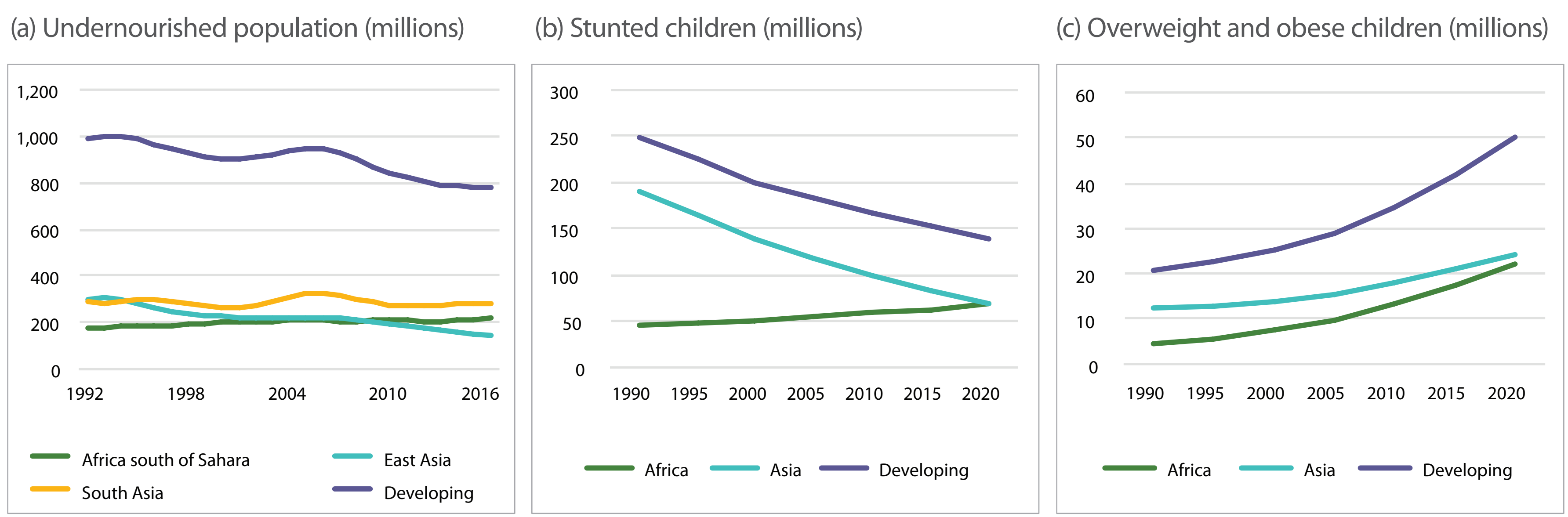
Source: United Nations, Department of Economic and Social Affairs, Population Division (2014, 2017).

projects that population in Africa will continue to grow rapidly throughout the 21st century. Africa's population is projected to exceed that of East Asia by the 2030s (at around 1.6 billion) and that of South Asia by midcentury (at around 2.3 billion). This growth will have direct effects on the demand for agricultural commodities, particularly staple food crops.

At the same time, Africa and other developing regions are projected to experience a continuing increase in per capita incomes (see, for example, Sulser et al. 2015) and a demographic shift from rural to urban areas, with two-thirds of the world's people living in urban areas by 2050 (Figure 2.1, panel [b]). Changing employment patterns, along with growth in incomes and increased globalization, have important implications for the nature of demand. Demand for traditional staples (excluding rice) is likely to slow in per capita terms as demand for purchased and processed foods increases.

These changing patterns of consumption affect food security and nutrition in diverse ways. Cheaper calories have reduced the number of undernourished people and of stunted children in much of the developing world but have not kept pace with population growth in Africa (Figure 2.2, panels [a] and [b]). At the same time, the number of overweight and obese children has increased in all regions, including Africa (Figure 2.2, panel [c]). Rising incomes improve access to higher-value foods such as fruits, vegetables, and animal-source foods for many, but these foods remain beyond reach for the poorest.

FIGURE 2.2—UNDERNOURISHMENT REMAINS A CHALLENGE IN AFRICA, EVEN WHILE OVERCONSUMPTION INCREASES



Source: FAO (2017); de Onis, Blossner, and Borghi (2010, 2012).

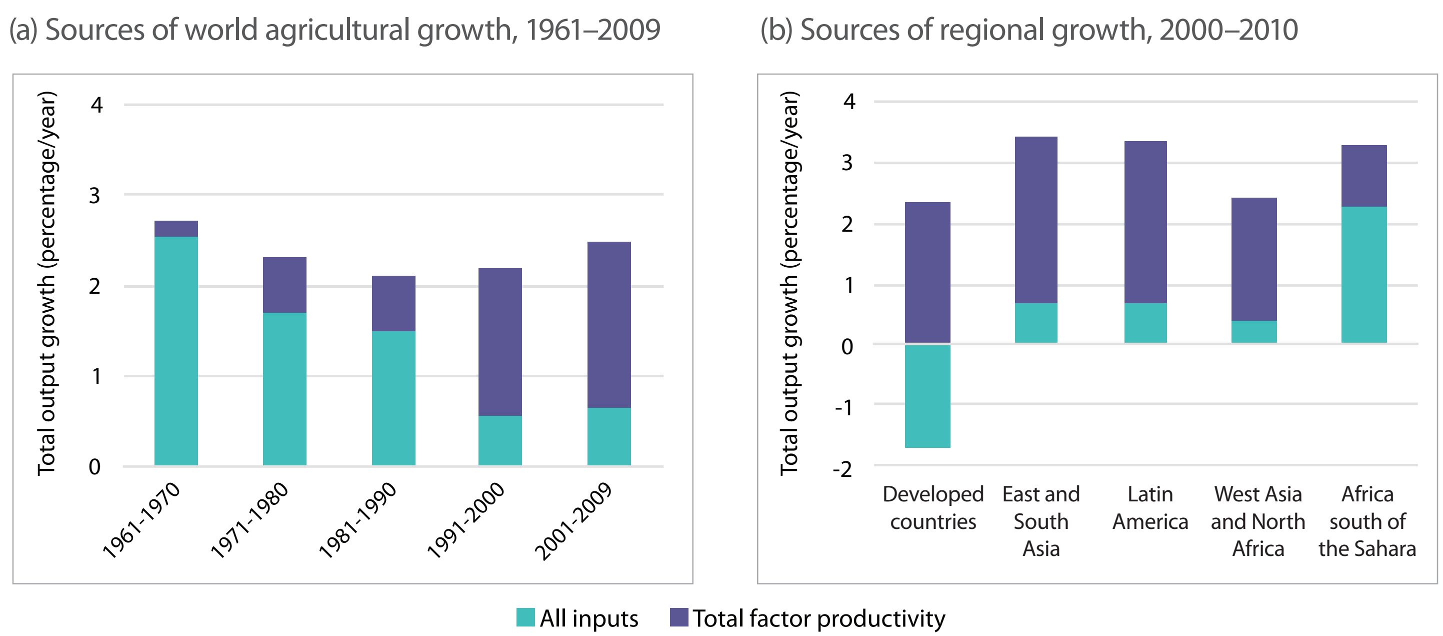
Supply Side: Land, Water, Infrastructure, and Technology

Whereas the level and composition of demand changes with population, income, and other factors, changes in natural resources and technology present new challenges and opportunities in meeting that demand. Over the past half century, growth in world agriculture has been driven increasingly by increases in total factor productivity, or the efficiency with which inputs such as land, water, and fertilizer are used (Figure 2.3, panel [a]). This is true in all regions except Africa south of the Sahara, where growth continues to be driven primarily by increases in agricultural inputs (Figure 2.3, panel [b]).

Because irrigation and commercial fertilizer use remain low in Africa south of the Sahara, soil nutrients are being depleted in many areas and crop yields also remain low. Cereal yields in Africa average about 1.5 tons[2] per hectare—only half of those in South Asia and 20–25 percent of those in East Asia and North America (Figure 2.4)—and maize yields represent only 20–50 percent of potential yields in the region (van Ittersum et al. 2016). These figures illustrate the challenge faced by the region but also the potential to be realized from improvements in productivity through increased investment in agricultural research, resource use efficiency, and infrastructure. We will return to these potential returns later.

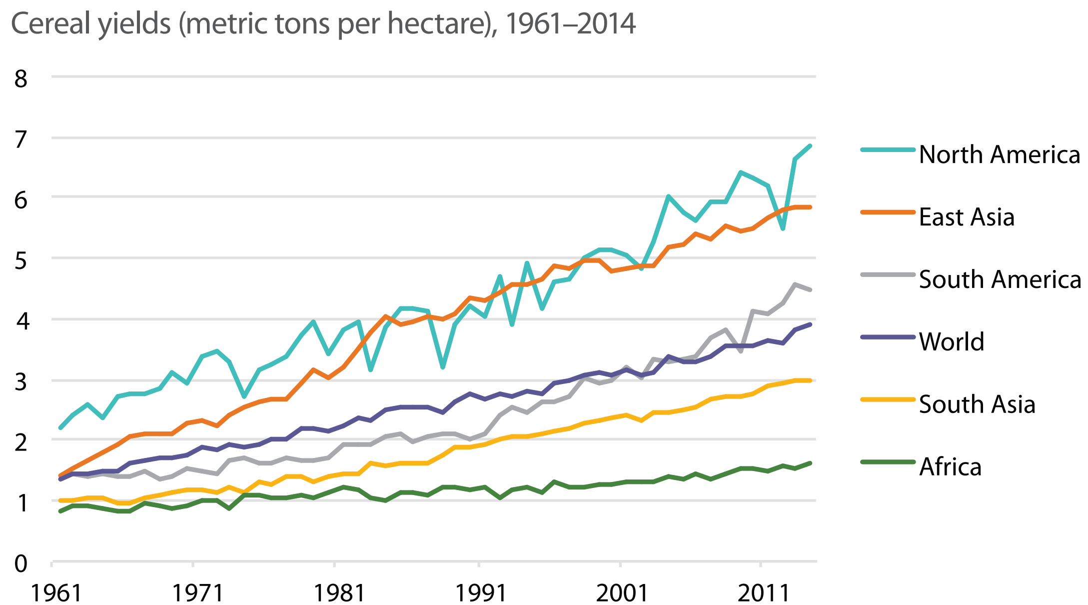
2 Throughout the chapter, *tons* refers to metric tons.

FIGURE 2.3—AFRICA LAGS BEHIND OTHER REGIONS IN AGRICULTURAL PRODUCTIVITY GROWTH



Source: Fuglie and Wang (2012), Fuglie and Rada (2013).

FIGURE 2.4—CROP YIELDS IN AFRICA REMAIN A FRACTION OF THOSE IN OTHER PARTS OF THE WORLD



Source: FAO (2017).

The Special Challenge of Climate Change

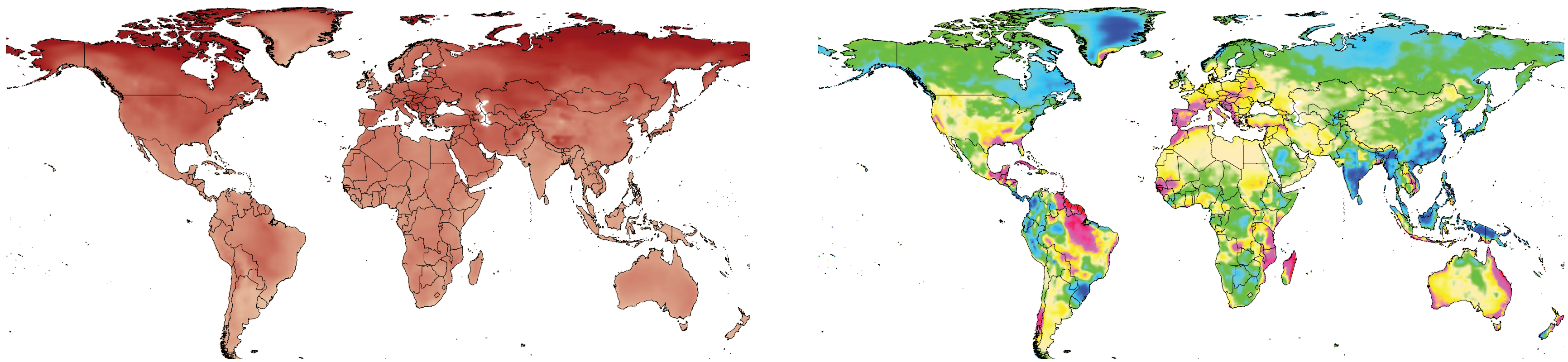
Compounding the effects of rising population and low productivity, climate change will present new challenges to Africa's farmers and consumers. Projections of impacts depend on general circulation models of Earth's climate and assumptions about the rate of change in greenhouse gas emissions in the coming decades. Details vary depending on the climate model and scenario considered, with general agreement on rising temperatures (Figure 2.5, panel [a]) but less consensus on how precipitation patterns will change (Figure2.5, panel [b]).

The combination of rising temperatures and changing precipitation patterns is projected to result in a wide range of impacts, including increases in weather volatility and extreme events, rising sea levels, changes in glacial meltwater flows (initially increasing and ultimately declining), changes in the incidence of agricultural pests and diseases, and direct effects on crop productivity. Many of these impacts are beyond our current ability to model at the global scale, but we are able to simulate the impact of expected changes in temperature and precipitation on crop yields at the local, regional, and global levels. To do so, we use projections from global climate models as inputs in crop simulation models such as the Decision Support

FIGURE 2.5—TEMPERATURES ARE PROJECTED TO RISE AND PRECIPITATION PATTERNS TO CHANGE

(a) Increase in temperature, 2050 relative to 2000

(b) Change in annual precipitation, 2050 relative to 2000



Source: Rosegrant and colleagues (2017), using the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model, assuming representative concentration pathway (RCP) 8.5.

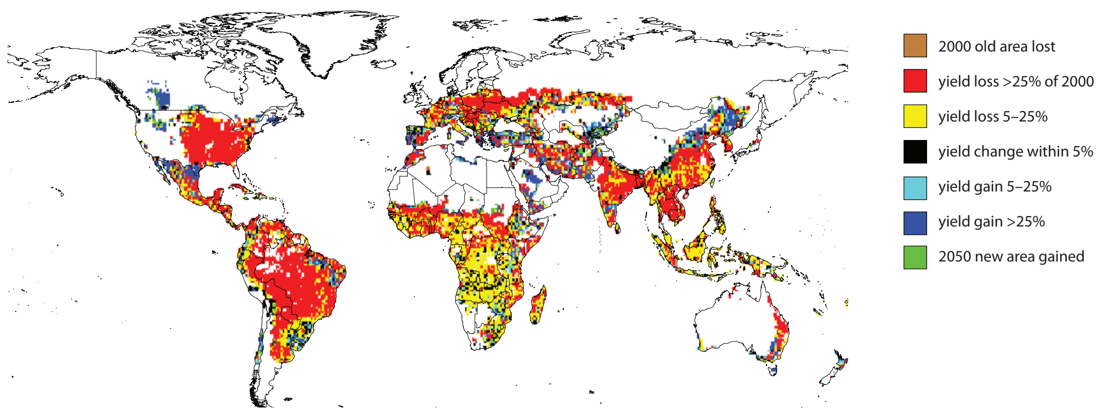
Note: The color gradient in panel (a) shows increases in maximum temperature in 2050 relative to 2000, from < 0˚C (white) to > 6˚C (dark red). The color gradient in (b) shows changes in annual precipitation in 2050 relative to 2000, from < -400 mm (dark red) to > 400 mm (dark blue).

System for Agrotechnology Transfer (DSSAT) to simulate impacts on yields under different climate scenarios. The results presented here are based on a scenario using the United Kingdom's Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones et al. 2011) and assuming relatively rapid increases in greenhouse gas emissions combined with middle-of-the-road assumptions about growth in population and incomes.[3] These results thus represent the impacts of relatively large changes in temperature and precipitation, but they omit the other dimensions of climate change noted above.

Yields of rainfed maize, for example, are projected to decline by as much as 25 percent or more in some regions under this scenario by 2050, relative to 2000 levels (Figure 2.6). It is essential to note that this projection is based on crop modeling that holds everything else constant—that is, it assumes that farmers continue to grow the same varieties in the same locations on the same planting calendar and using the same management practices. But we know that farmers won't continue to do everything the same as before—not only because they will respond to changing climate conditions but also because market conditions and technologies will also be changing in the coming decades.

3 Specifically, these results assume climate change as represented by representative concentration pathway (RCP) 8.5 and shared socioeconomic pathway (SSP) 2. See Moss and others (2008) and O'Neill and others (2014) for more information.

FIGURE 2.6—MAIZE YIELDS WILL BE HARD HIT BY CLIMATE CHANGE (YIELDS EXPRESSED AS PERCENTAGE OF 2000 LEVELS)



Source: Robertson (2015).

Note: Decision Support System for Agrotechnology Transfer (DSSAT) crop model results for rainfed maize based on the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) model and representative concentration pathway (RCP) 8.5 for 2050, before economic adjustments.

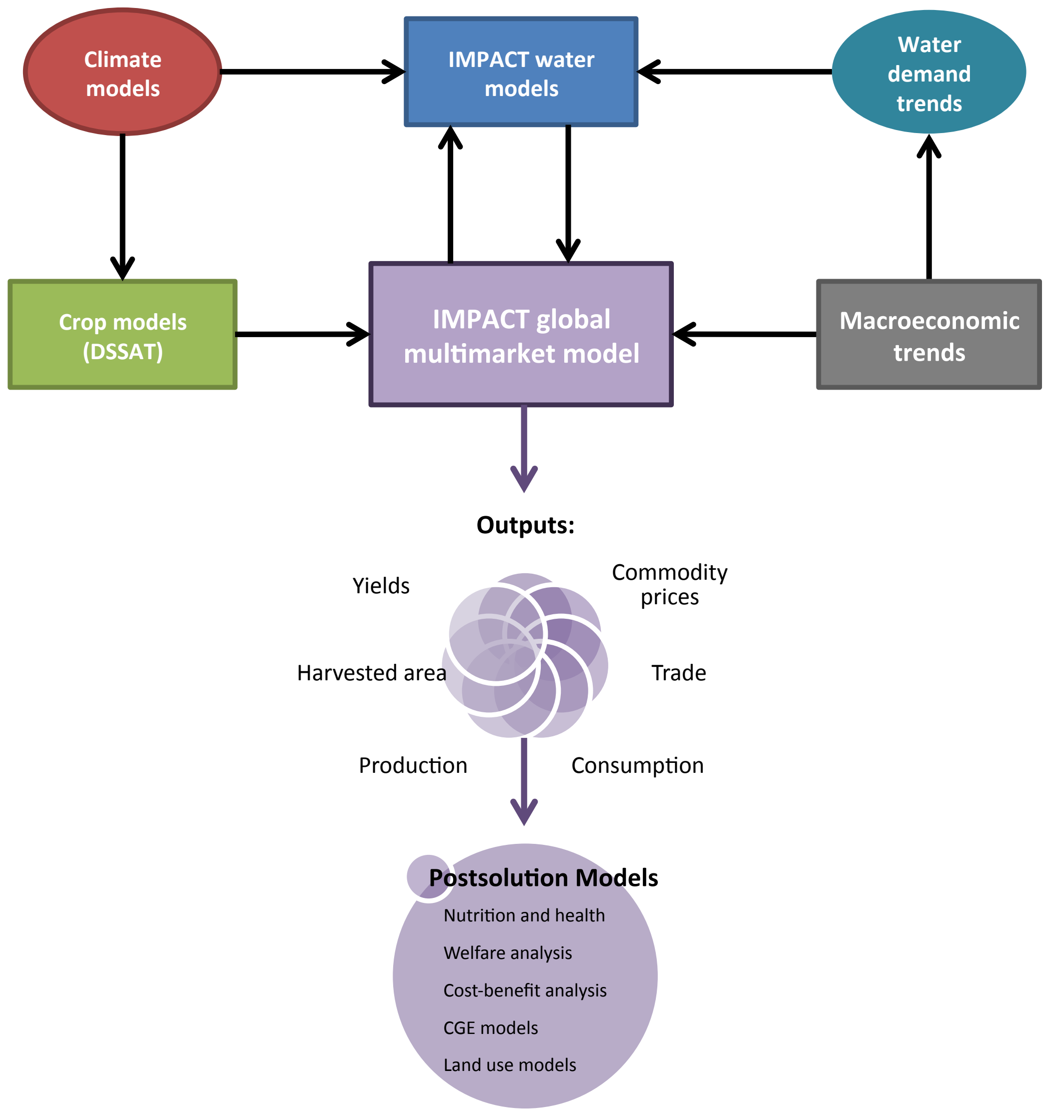
This chapter explores the future impacts of these various changes, incorporating economic adjustments. The following sections present baseline projections for agriculture and food in Africa to 2050 based on changes in the driving factors described here, and then explore how these projected outcomes can be changed by decisions we make today, specifically in relation to investment in agricultural research, natural resource management, and infrastructure.

Baseline Projections for Production, Area, Yield, Consumption, Prices, Trade, Hunger, and the Environment to 2050

The IMPACT System of Models

To explore how changes in population, income, technology, climate, investment, and policy will affect agriculture and food in Africa in the coming decades, we use a system of models developed by the International Food Policy Research Institute (IFPRI), called the International Model for Policy

FIGURE 2.7—THE IMPACT SYSTEM OF MODELS



Source: Robinson and others (2015).

Note: CGE = computable general equilibrium; DSSAT = Decision Support System for Agrotechnology Transfer; IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

Analysis of Agricultural Commodities and Trade (IMPACT) (Figure 2.7). IMPACT is a linked system of climate, water, crop, and economic models designed to explore the impacts of changes in population, income, technology, climate, and other factors on agricultural production, resource use, trade, and food security (Rosegrant et al. 2008). IMPACT has been further developed in recent years through ongoing collaboration among the 15 CGIAR Centers and with other climate, crop, and economic modeling groups through the Agricultural Model Intercomparison and Improvement Project (Robinson et al. 2015).[4]

Baseline Projections for Africa South of the Sahara

Using the IMPACT model with standard assumptions on changes in population, income, and climate as reflected in shared socioeconomic pathway (SSP) 2 and representative concentration pathway (RCP) 8.5, together with moderate growth in agricultural productivity, IFPRI recently released a new set of baseline projections of agricultural production, food consumption, trade, and risk of hunger in its *2017 Global Food Policy Report* (IFPRI 2017). Selected results from those projections

[4] More details on the IMPACT model and methodology can be found at www.ifpri.org/program/impact-model.

TABLE 2.1— IMPACT PROJECTIONS OF CEREAL AND MEAT PRODUCTION, CONSUMPTION, AND TRADE TO 2050

Food group / region	Total production (million metric tons)					Per capita food consumption (kg per capita per year)					Net trade (million metric tons)				
	Without climate change			With climate change		Without climate change			With climate change		Without climate change			With climate change	
	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050
Cereals															
World	**2,155**	**2,746**	**3,235**	**2,621**	**2,990**	**143.5**	**146.7**	**148.3**	**143.4**	**140.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**151**	**230**	**303**	**220**	**279**	**139.9**	**143.8**	**145.9**	**138.9**	**136.2**	**-59.7**	**-106.6**	**-185.0**	**-103.2**	**-169.2**
West	49	79	110	75	99	143.5	152.4	155.3	146.9	144.8	-13.7	-29.8	-60.3	-29.1	-56.9
Central	7	12	18	12	17	59.3	65.4	68.9	62.4	63.0	-3.1	-6.3	-11.8	-5.9	-10.5
East	39	65	91	64	91	115.7	125.6	134.1	119.7	123.1	-8.7	-17.1	-31.9	-13.7	-21.8
Southern	13	18	21	19	23	182.8	194.8	201.5	187.5	187.3	-3.5	-7.1	-12.5	-4.6	-7.2
Northern	42	55	62	49	50	204.7	202.5	198.7	199.6	191.0	-30.6	-46.4	-68.5	-49.9	-72.8
Meats															
World	**274**	**381**	**460**	**380**	**455**	**39.4**	**45.6**	**49.5**	**45.4**	**49.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**14**	**27**	**45**	**27**	**45**	**14.7**	**20.1**	**28.4**	**20.0**	**28.1**	**-0.9**	**-3.9**	**-12.4**	**-3.8**	**-11.9**
West	3	6	11	6	11	10.2	16.2	26.6	16.1	26.3	-0.3	-1.9	-7.3	-1.9	-7.1
Central	1	1	2	1	2	9.1	12.2	17.0	12.1	16.8	-0.4	-1.0	-2.1	-1.0	-2.0
East	3	6	10	6	10	10.3	14.4	22.5	14.3	22.2	0.0	-1.1	-4.9	-1.1	-4.7
Southern	2	4	5	4	5	45.2	61.0	73.3	60.8	72.7	-0.2	-0.1	-0.1	-0.1	-0.1
Northern	5	10	17	10	17	22.6	32.0	42.9	31.9	42.7	0.0	0.3	2.0	0.3	2.0
Fruits and vegetables															
World	**1,592**	**2,334**	**3,044**	**2,297**	**2,945**	**196.2**	**240.0**	**284.7**	**236.2**	**275.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**153**	**276**	**435**	**255**	**378**	**121.8**	**141.7**	**166.5**	**139.1**	**160.2**	**2.2**	**12.8**	**22.1**	**-3.1**	**-18.4**
West	40	74	118	70	106	117.2	145.3	174.4	142.4	167.9	0.3	-3.5	-14.8	-6.0	-22.1
Central	10	17	27	16	22	66.0	82.4	103.1	80.2	97.7	0.1	-1.3	-4.4	-2.5	-7.5
East	36	70	121	65	107	82.2	105.5	138.5	103.2	132.4	-1.2	-5.4	-12.9	-8.1	-20.3
Southern	9	15	21	14	17	76.2	89.2	98.3	87.4	94.3	2.9	6.4	10.1	5.2	7.2
Northern	57	99	149	90	126	228.9	250.1	270.3	246.7	262.9	0.0	16.5	44.1	8.3	24.4

Source: IMPACT version 3.3 results from IFPRI (2017).

Notes: World figures include other regions not reported separately. Country-level details are available online at https://dataverse.harvard.edu/dataverse/impact. Total production is aggregated across irrigated and rainfed systems at the national level and aligned with years as reported in FAOSTAT, the statistical database of the Food and Agriculture Organization of the United Nations. Per capita food consumption is based on food availability at the national level. Net trade includes negative and positive numbers indicating that a region is a net importer or exporter, respectively, and balances to 0 at the global level. Cereals include barley, maize, millet, rice, sorghum, wheat, and aggregated other cereals. Meats include beef, pork, poultry, and sheep and goats. Fruits and vegetables include bananas, plantains, aggregated temperate fruits, aggregated tropical fruits, and aggregated vegetables. Oilseeds include groundnut, rapeseed, soybean, sunflower, and aggregated other oilseeds. Pulses include beans, chickpeas, cowpeas, lentils, pigeon peas, and aggregated other pulses. Roots and tubers include cassavas, potatoes, sweet potatoes, yams, and aggregated other roots and tubers. Values reported for 2010 are calibrated model results. Projections for 2030 and 2050 assume changes in population and income as reflected in the Intergovernmental Panel on Climate Change's (IPCC's) shared socioeconomic pathway (SSP) 2. Climate change impacts are simulated using the IPCC's representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model. Further documentation is available at www.ifpri.org/program/impact-model. IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

TABLE 2.1— IMPACT PROJECTIONS OF CEREAL AND MEAT PRODUCTION, CONSUMPTION, AND TRADE TO 2050, *continued*

Food group / region	Total production (million metric tons)					Per capita food consumption (kg per capita per year)					Net trade (million metric tons)				
	Without climate change			With climate change		Without climate change			With climate change		Without climate change			With climate change	
	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050
Oilseeds															
World	**673**	**1,033**	**1,293**	**1,017**	**1,257**	**6.8**	**8.2**	**7.8**	**7.9**	**7.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**56**	**94**	**118**	**91**	**110**	**5.7**	**6.7**	**7.5**	**6.4**	**6.9**	**-1.2**	**-2.7**	**-6.3**	**-2.4**	**-5.4**
West	43	74	94	72	88	8.1	9.3	10.1	8.8	9.2	0.3	-0.5	-2.7	-0.4	-2.5
Central	4	6	8	6	7	9.0	10.0	10.6	9.4	9.5	0.1	0.1	0.1	0.2	0.4
East	4	6	7	6	7	3.7	4.4	5.3	4.2	4.8	0.1	-0.3	-1.3	-0.2	-0.9
Southern	1	1	2	1	1	1.9	2.1	2.1	2.0	2.0	-0.2	-0.3	-0.3	-0.2	-0.2
Northern	4	6	7	5	6	4.6	5.3	5.7	5.1	5.3	-1.5	-1.8	-2.2	-1.7	-2.1
Pulses															
World	**66**	**94**	**121**	**92**	**118**	**6.2**	**7.5**	**8.9**	**7.5**	**8.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**13**	**20**	**30**	**20**	**28**	**10.0**	**12.0**	**14.3**	**11.8**	**14.0**	**-1.7**	**-5.2**	**-11.1**	**-5.4**	**-11.5**
West	5	9	16	9	14	8.5	9.8	11.6	9.6	11.1	0.3	0.1	-0.3	0.0	-0.6
Central	1	2	2	2	2	6.7	7.4	8.7	7.3	8.4	-0.1	-0.2	-0.3	-0.2	-0.2
East	5	7	9	7	10	15.3	18.2	22.0	18.0	21.6	-0.7	-3.3	-7.9	-3.2	-7.5
Southern	0	0	0	0	0	3.8	4.2	4.5	4.1	4.4	-0.1	-0.1	0.0	-0.1	0.0
Northern	1	2	2	1	2	8.2	9.7	11.4	9.8	11.5	-1.1	-1.8	-2.6	-2.1	-3.2
Roots and tubers															
World	**780**	**1,006**	**1,185**	**963**	**1,103**	**65.0**	**70.5**	**73.4**	**67.8**	**69.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**232**	**362**	**506**	**346**	**469**	**129.0**	**138.0**	**143.7**	**134.4**	**137.0**	**-0.7**	**-10.2**	**-28.3**	**-15.1**	**-37.8**
West	133	207	297	201	281	197.5	199.0	198.8	194.9	191.1	1.5	-4.3	-11.7	-4.2	-10.2
Central	37	59	80	56	72	172.5	170.6	166.7	167.1	159.9	1.0	2.6	-2.2	0.1	-8.2
East	50	78	107	71	91	129.6	138.5	142.0	134.6	134.4	-3.2	-9.4	-15.3	-13.9	-24.6
Southern	3	4	5	4	5	36.8	37.7	38.7	36.6	37.1	0.0	0.7	1.3	0.9	1.3
Northern	9	14	18	15	20	33.7	38.3	42.1	35.7	37.9	-0.1	0.2	-0.3	2.0	4.0

Source: IMPACT version 3.3 results from IFPRI (2017).

Notes: World figures include other regions not reported separately. Country-level details are available online at https://dataverse.harvard.edu/dataverse/impact. Total production is aggregated across irrigated and rainfed systems at the national level and aligned with years as reported in FAOSTAT, the statistical database of the Food and Agriculture Organization of the United Nations. Per capita food consumption is based on food availability at the national level. Net trade includes negative and positive numbers indicating that a region is a net importer or exporter, respectively, and balances to 0 at the global level. Cereals include barley, maize, millet, rice, sorghum, wheat, and aggregated other cereals. Meats include beef, pork, poultry, and sheep and goats. Fruits and vegetables include bananas, plantains, aggregated temperate fruits, aggregated tropical fruits, and aggregated vegetables. Oilseeds include groundnut, rapeseed, soybean, sunflower, and aggregated other oilseeds. Pulses include beans, chickpeas, cowpeas, lentils, pigeon peas, and aggregated other pulses. Roots and tubers include cassavas, potatoes, sweet potatoes, yams, and aggregated other roots and tubers. Values reported for 2010 are calibrated model results. Projections for 2030 and 2050 assume changes in population and income as reflected in the Intergovernmental Panel on Climate Change's (IPCC's) shared socioeconomic pathway (SSP) 2. Climate change impacts are simulated using the IPCC's representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model. Further documentation is available at www.ifpri.org/program/impact-model. IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

are presented in Tables 2.1 and 2.2.[5] Given the complexity and uncertainty inherent in the underlying processes involved, it is important to note that projections vary depending on the specific models and assumptions used. Those presented here represent current baselines with and without climate change, but work is under way to analyze a wider range climate and socioeconomic assumptions (Wiebe et al. 2015).

Cereal production is projected to double in Africa south of the Sahara by midcentury, but production in 2050 will be about 5 percent less than it would have been in the absence of climate change. (These results assume moderate growth in agricultural productivity—an assumption that can be adjusted according to decisions made regarding investment in agricultural research and development.) Net imports of cereals in the region are projected to increase threefold relative to 2010 levels. Perhaps counterintuitively, net cereal imports into the region are projected to be lower in 2050 with climate change than they would have been in the absence of climate change. This is because in this scenario, based on climate results from HadGEM2-ES, temperature increases and changes in precipitation reduce growth in production by the major cereal-producing and -exporting countries in the Americas and Europe (Figure 2.6), thereby raising prices.[6] Higher prices will in turn reduce cereal imports by African and other developing countries. The

5 The full set of results can be found online at https://dataverse.harvard.edu/dataverse/impact.

6 Increased levels of atmospheric carbon dioxide increase plant productivity under certain circumstances and may partially offset some adverse impacts of climate change, but their effects are sensitive to other factors and remain controversial (Nowak 2017; Obermeier and colleagues 2016), and therefore they are not included in the scenarios described here.

TABLE 2.2— IMPACT PROJECTIONS OF FOOD PRODUCTION, CONSUMPTION, AND HUNGER TO 2050

Region	Aggregate food production (index, 2010 = 1.00)					Per capita food consumption (KCAL per capita per day)					Hunger (millions of people at risk)				
	Without climate change			With climate change		Without climate change			With climate change		Without climate change			With climate change	
	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050
World	**1.00**	**1.37**	**1.69**	**1.33**	**1.60**	**2,795**	**3,032**	**3,191**	**2,982**	**3,079**	**838.1**	**528.2**	**405.8**	**592.3**	**476.9**
Africa	**1.00**	**1.63**	**2.32**	**1.55**	**2.12**	**2,505**	**2,709**	**2,947**	**2,642**	**2,810**	**215.5**	**202.2**	**157.4**	**229.7**	**196.0**
West	1.00	1.65	2.36	1.59	2.19	2,637	2,853	3,056	2,778	2,909	30.1	28.0	29.0	32.5	33.5
Central	1.00	1.66	2.33	1.56	2.07	2,101	2,432	2,843	2,366	2,701	52.3	36.5	21.2	43.2	25.4
East	1.00	1.68	2.50	1.59	2.28	2,110	2,345	2,629	2,273	2,488	112.1	115.6	89.2	130.6	116.3
Southern	1.00	1.50	1.87	1.49	1.81	2,881	3,134	3,308	3,059	3,165	3.8	3.0	2.3	3.3	2.8
Northern	1.00	1.56	2.14	1.43	1.85	3,029	3,182	3,360	3,137	3,254	17.2	19.1	15.9	20.2	18.0

Source: IMPACT version 3.3 results from IFPRI (2017).

Notes: World figures include other regions not reported separately. Country-level details are available online at https://dataverse.harvard.edu/dataverse/impact. Aggregate food production is an index, by weight, of cereals, meats, fruits and vegetables, oilseeds, pulses, and roots and tubers (which are reported separately in Table 2.1). Per capita food consumption is a projection of daily dietary energy supply in kilocalories. Estimates of the number of people at risk of hunger are based on a quadratic specification of the relationship between national-level calorie supply and the share of population that is undernourished as defined by the Food and Agriculture Organization of the United Nations. Values reported for 2010 are calibrated model results. Projections for 2030 and 2050 assume changes in population and income as reflected in the Intergovernmental Panel on Climate Change's (IPCC's) shared socioeconomic pathway (SSP) 2. Climate change impacts are simulated using the IPCC's representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model. Further documentation is available at www.ifpri.org/program/impact-model. IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

combined impact of increased population, slower growth in production due to climate change, and imports that are lower than they would have been in the absence of climate change means that per capita consumption of cereals will remain basically unchanged in the region in 2050 relative to 2010.

Meat production in Africa south of the Sahara is projected to grow by around 24 million tons (a threefold increase) by 2050, and net imports are projected to grow from less than 1 million tons to around 13 million tons, resulting in a doubling of per capita meat consumption.

Pulse production in the region is projected to more than double, and net imports are projected to grow from less than 1 million tons to around 9 million tons. Per capita consumption is projected to rise by about a third.

Root and tuber production in the region is projected to double, and net imports are projected to grow from around 1 million tons to 43 million tons by 2050. Per capita consumption will remain basically unchanged, at around 150 kg per capita per year.

Oilseed production will also double, to 105 million tons, with a small increase in net imports, to around 4 million tons, and relatively little change in per capita consumption.

Fruit and vegetable production in the region is projected to increase by 1.6 times by 2050, and per capita consumption by half. The region is projected to become a net importer of fruits and vegetables, with about one-quarter of total demand being met by imports.

Based on the combined effects of changes in population, income, climate, and productivity, the number of people at risk of hunger in Africa south of the Sahara is projected to decline from 209.5 million in 2010 to 188.7 million in 2050 in this scenario (Table 2.2). Projected improvements are greatest in central Africa, with slight increases in the number at risk in eastern and western Africa. Climate change reduces the improvement that would be projected in the absence of climate change, leaving 38 million more people at risk of hunger in Africa south of the Sahara in 2050 than would otherwise be the case, most of them in eastern Africa. And the malnutrition rate for children younger than five years (as measured by wasting) is projected to rise from 21.7 to 24.4 percent by 2050—an increase of more than 4 million children (Waithaka et al. 2013; Jalloh et al. 2013; Hachigonta et al. 2013; Thomas and Rosegrant 2015).

Gains from Improvements in Productivity, Resource Management, and Infrastructure

Adoption of Improved Agricultural Technologies for Sustainable Intensification

Rosegrant and colleagues (2014) analyzed a wide range of agricultural technologies selected for their potential to improve productivity while reducing adverse environmental impacts. Approaches ranging from new stress-tolerant crop varieties to no-till and precision agriculture were simulated worldwide for maize, rice, and wheat crops, under a warmer and wetter future climate scenario.

In Africa south of the Sahara, among the technologies considered, no-till farming and nitrogen-efficient crop varieties show the greatest promise under a warmer and wetter climate in 2050, compared with a scenario without adoption of those technologies (Table 2.3). Overall, rice yields in Africa south of the Sahara receive the largest boost through the use of nitrogen-use-efficient varieties (+21 percent), whereas no-till farming is the most favorable technology for both maize (+15 percent) and wheat (+17 percent).

Increased production and lower prices due to adoption of improved technologies translates into better access to food, and simulations show a potential reduction in the population at risk of hunger of up to 11 percent in Africa south of the Sahara (Figure 2.8).

Islam and others (2016) also examined the potential impact of adoption of drought- and heat-tolerant crop varieties, including maize and groundnuts, in selected countries of Africa south of the Sahara. They found that in many cases the new technologies are projected to more than offset the adverse impacts of climate change on yields for those crops and countries—at least through the duration of the projected period (to 2050). Farmers and countries that adopt the new technologies improve their productivity faster than projected increases in demand, which improves those countries' terms of trade.

Although such technologies show promise in terms of increased productivity and food security, their adoption, particularly by poor smallholder farmers in Africa south of the Sahara, is often limited by well-known barriers in the form of poor access to resources; information; and markets for inputs, outputs, and risk-management tools. Overcoming these barriers will require major investment in research and technology as well as in the institutional and physical infrastructure

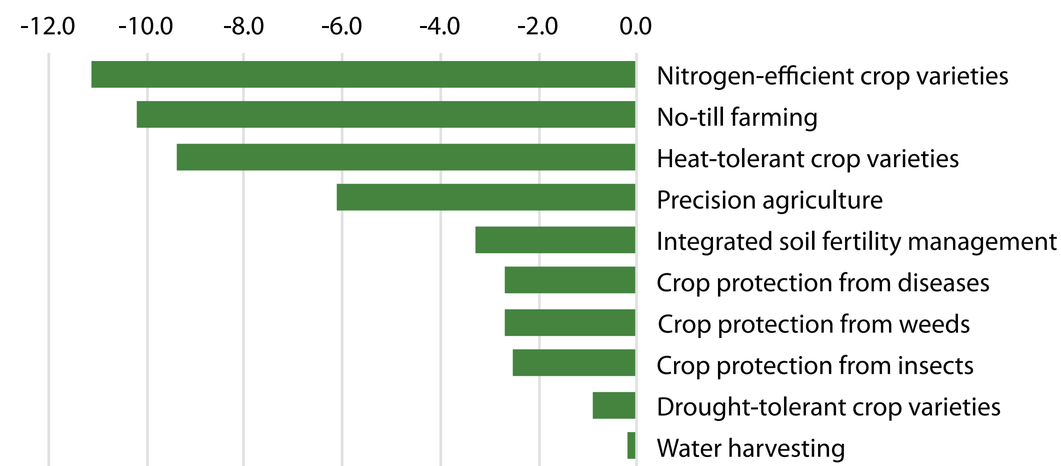
TABLE 2.3—PERCENTAGE CHANGE IN YIELDS FOR MAIZE, RICE, AND WHEAT IN AFRICA SOUTH OF THE SAHARA, COMPARED WITH BASELINE WITHOUT ADOPTION OF IMPROVED TECHNOLOGIES, 2050

Technology	Maize	Rice	Wheat
Nitrogen-efficient crop varieties	7.9	20.9	4.4
No-till farming	15.0	-0.4	17.1
Heat-tolerant crop varieties	3.5	0.2	4.5
Precision agriculture	-0.6	7.9	6.2
Integrated soil fertility management	5.8	5.7	6.1
Crop protection from diseases	4.4	10.5	2.6
Crop protection from weeds	6.5	10.3	2.1
Crop protection from insects	4.9	11.7	1.9
Drought-tolerant crop varieties	3.5	0.4	2.6
Water harvesting	0.6	0.0	0.9

Source: Rosegrant and colleagues (2014).

Note: International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) simulations under Model for Interdisciplinary Research on Climate (MIROC) scenario A1B (a wetter and warmer climate).

FIGURE 2.8—PERCENTAGE CHANGE IN POPULATION AT RISK OF HUNGER IN AFRICA SOUTH OF THE SAHARA, COMPARED WITH BASELINE WITHOUT ADOPTION OF IMPROVED TECHNOLOGIES, 2050



Source: Rosegrant and colleagues (2014).

Note: International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) simulations under Model for Interdisciplinary Research on Climate (MIROC) scenario A1B (a wetter and warmer climate).

needed to improve access to new opportunities. Recent findings on the impacts of such investments are described in the next section.

Investment in Productivity-Enhancing Research and Development, Water Management, and Infrastructure

A recent analysis by Rosegrant and colleagues (2017) in collaboration with the 15 CGIAR Centers examined three sets of alternative investment scenarios for the developing world, each of which increases investment in one of the areas described in the previous section. A fourth comprehensive scenario combines elements from the first three:

1. Enhanced productivity through increased investments in agricultural research and development (R&D). Five scenarios explore the impacts of different levels of increased investment in research by CGIAR and national agricultural research systems, with different regional emphases, to help overcome the disparities in productivity growth evident in Figure 2.4, particularly in Africa south of the Sahara and South Asia.
2. Improved water resource management. Three scenarios explore the impacts of increased investment to expand irrigated area, increase water use efficiency, and increase the water-holding capacity of soil.
3. Improved marketing efficiency through increased investment in infrastructure. One scenario explores the impact of increased investment in transportation and marketing infrastructure to reduce price margins between producers and consumers.
4. A comprehensive scenario combining selected elements of 1–3.

Scenarios were run to 2050, but we focus here on results for 2030, which is the time frame for the Sustainable Development Goals. Globally, we project that crop yields would increase by 30 percent, on average, by 2030 over 2010 levels in a baseline scenario without climate change or additional investments, but climate change is projected to reduce this increase to 25 percent (Table 2.4). The comprehensive portfolio of investments in agricultural research, improved resource management, and improved infrastructure (#4 in the list above) would more than offset the adverse impacts of climate change through 2030 and would increase average crop yields by 35 percent over 2010 levels.[7] (Note that adverse impacts of climate change, though already occurring, are relatively modest through 2030 and even through midcentury, but are projected to accelerate thereafter.)

Similar patterns are projected for developing countries and for Africa, with average yield increases of 32–43 percent by 2030 in the absence of climate change, reductions of 4–9 percentage points due to climate change, and overall increases of 40–56 percent with a comprehensive investment portfolio. With such investment, yields in Africa are projected to grow more rapidly than those in other developing regions, with average increases of 47–56 percent, compared with 40 percent for developing countries as a whole and 35 percent globally.

Based on these increased yields (together with smaller increases in cropland area), food availability in terms of dietary energy is projected to increase by 2030 globally and in all regions of Africa (Table 2.5). The overall

[7] Increasing investment in agricultural R&D, resource use efficiency, and marketing efficiency separately rather than as part of a comprehensive package would cost less but would also offer lower benefits. In some cases it would also generate trade-offs between different goals, for example in the case of improved marketing efficiency, which would increase agricultural production and lower food prices but also expand forestland conversion and greenhouse gas emissions. More on these scenarios can be found in Rosegrant and colleagues (2017).

TABLE 2.4—AVERAGE CROP YIELDS IN 2030 (INDEXED, 2010 = 1.0), BY REGION AND SCENARIO

Region	2010	2030, no CC	2030, CC	2030, COMP
World	1.00	1.30	1.25	1.35
Developing countries	1.00	1.32	1.28	1.40
Africa	1.00	1.35	1.28	1.51
Northern Africa	1.00	1.35	1.24	1.48
Africa south of the Sahara	1.00	1.35	1.28	1.52
Western Africa	1.00	1.36	1.30	1.53
Eastern Africa	1.00	1.38	1.31	1.56
Central Africa	1.00	1.32	1.23	1.47
Southern Africa	1.00	1.43	1.40	1.54

Source: Mason-D'Croz and others (2016).

Note: No CC assumes no climate change (a constant 2005 climate); CC reflects a future with climate change using representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones and others 2011); COMP refers to a scenario with climate change and a comprehensive investment portfolio as described above.

pattern is similar to that of crop yields, with projected increases slowed by climate change but adverse climate impacts offset by the effects of increased investment. In the latter case, kilocalorie availability per capita per day is projected to increase by more than 10 percent, to 2,834, for Africa as a whole, with subregional averages ranging from around 2,500 kilocalories per capita per day in eastern and central Africa to more than 3,000 kilocalories per capita per day in northern, southern, and western Africa.

Because of rapid population growth, the prevalence of hunger declines only slightly by 2030 in the case of no climate change, and actually increases in the climate change baseline (Table 2.6). Increased investment is projected to reduce the number of people at risk of hunger in Africa, in terms of average caloric deficiency, to 161 million by 2030, representing a decline of

TABLE 2.5—AVERAGE FOOD SUPPLY (KILOCALORIES PER CAPITA PER DAY) IN 2010 AND 2030, BY REGION AND SCENARIO

Region	2010	2030, no CC	2030, CC	2030, COMP
World	1.00	1.30	1.25	1.35
Developing countries	1.00	1.32	1.28	1.40
Africa	1.00	1.35	1.28	1.51
Northern Africa	1.00	1.35	1.24	1.48
Africa south of the Sahara	1.00	1.35	1.28	1.52
Western Africa	1.00	1.36	1.30	1.53
Eastern Africa	1.00	1.38	1.31	1.56
Central Africa	1.00	1.32	1.23	1.47
Southern Africa	1.00	1.43	1.40	1.54

Source: Mason-D'Croz and others (2016).

Note: No CC assumes no climate change (a constant 2005 climate); CC reflects a future with climate change using representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones and others 2011); COMP refers to a scenario with climate change and a comprehensive investment portfolio as described above. The horizontal axis at 1,800 kilocalories per capita per day represents the daily minimum requirement; 2,400 is the recommended daily consumption for an active 20- to 35-year-old female and 3,000 is the recommended daily consumption for an active 20- to 35-year-old male.

TABLE 2.6—PREVALENCE OF HUNGER IN 2010 AND 2030 (MILLIONS OF PEOPLE)

Region	2010	2030, no CC	2030, CC	2030, COMP
World	838	528	598	416
Developing countries	823	513	582	403
Africa	215	202	231	161
Northern Africa	17	19	20	16
Africa south of the Sahara	209	196	224	155
Western Africa	30	28	33	22
Eastern Africa	112	116	131	98
Central Africa	52	36	43	23
Southern Africa	4	3	3	3

Source: Mason-D'Croz and others (2016).

Note: No CC assumes no climate change (a constant 2005 climate); CC reflects a future with climate change using representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones and others 2011); COMP refers to a scenario with climate change and a comprehensive investment portfolio as described above.

30 percent relative to 2010 levels, with the largest numeric improvement (33 million) in eastern Africa and the largest percentage improvement (nearly 50 percent) in central Africa.

The share of the population at risk of chronic hunger is projected to remain at more than 10 percent in Africa by 2030 in the absence of climate change (Table 2.7). The share is lower in western and southern Africa and higher in eastern Africa. Climate change reverses these gains in Africa, as in other regions, but its effects can be offset by a comprehensive set of investments in agricultural research, resource management, and infrastructure. It is important to note that the assessments of population at risk of chronic hunger are based on the average availability of food energy and do not take into account other dimensions of food insecurity such as micronutrient deficiencies, episodes of conflict, or other shocks that create localized vulnerability.

TABLE 2.7—PREVALENCE OF HUNGER IN 2010 AND 2030 (AS A SHARE OF THE TOTAL POPULATION, PERCENTAGE)

Region	2010	2030, no CC	2030, CC	2030, COMP
World	12.2	6.4	7.2	5.0
Developing countries	14.3	7.4	8.3	5.7
Africa	20.9	13.2	15.0	10.5
Northern Africa	7.7	6.5	6.9	5.5
Africa south of the Sahara	24.3	14.8	16.9	11.7
Western Africa	9.9	5.8	6.9	4.6
Eastern Africa	34.9	23.2	26.4	19.7
Central Africa	41.3	18.2	21.6	11.5
Southern Africa	6.6	4.4	4.9	3.7

Source: Mason-D'Croz and others (2016).

Note: No CC assumes no climate change (a constant 2005 climate); CC reflects a future with climate change using representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones and others 2011); COMP refers to a scenario with climate change and a comprehensive investment portfolio as described above.

Discussion, Institutional and Political Challenges, and Conclusion

In the face of a growing threat to food security, policy makers are under increasing pressure to devise policies that promote adaptation to climate change while also reducing greenhouse gas emissions. These policies need to address the local impacts of global change and must be feasible in the short term and sustainable in the long term, designed to weather challenges from forces that are both global and local, exogenous and endogenous to a country (De Pinto, Wiebe, and Rosegrant 2016). Recent analyses offer insights on alternative scenarios and inform the consideration of policy options that can contribute to a country's climate-change readiness. A global-to-local approach also helps in identifying climate opportunities—that is, places where climate change will improve conditions for agriculture—as well as which crops to invest in, given changes in comparative advantage and commodity prices.

In the years ahead, up to 2050, African countries are projected to continue the substantial growth observed in recent decades. Many will enter middle-income status. Agriculture will grow absolutely and decline as a share of national economies as services and manufacturing increase more rapidly than primary agriculture. In order to engage constructively in the process of structural transformation and growth, African agriculture will need to become technologically more sophisticated and derive more benefit from a strong foundation in agricultural science. A vibrant scientific establishment will facilitate sectoral adaptation to changing conditions of the climate and markets, and create jobs for young people seeking to share in the national transition to middle-income status. This is all the more important because climate change impacts will accelerate after midcentury, and—uniquely among world regions—population will continue to grow in Africa south of the Sahara throughout the 21st century.

Many of the issues that African farmers will confront are regional in nature, due to both increased integration of markets and regional dimensions of shifts in agroecology. Thus, the scientific effort to facilitate agriculture's contribution to growth must be regional in design. Given the weak foundation of agricultural science in the region at present, the effort to rebuild will require focused and targeted training and investment. Improvements are also needed in modeling tools to address the impacts of increases in weather volatility and extreme events, rising sea levels, and changes in the incidence of agricultural pests and diseases, as well as to better account for uncertainty and the costs involved in addressing these challenges. The foresight analysis presented above and subsequent refinements of the work can serve as a platform for rigorous consideration of investment alternatives. Foresight analysis can also provide early warning of locally specific agricultural challenges, thereby facilitating planning to assist affected populations, as well as highlight new opportunities.