Chapter 4

Integrated Assessment Modeling of Agricultural and Food Systems

Key Chapter Findings

- Climate-change effects on overall global food production are likely to be detrimental, particularly later in the century, but these effects vary substantially by region.
- The most adverse effects are likely to occur in the tropics and subtropics, with some benefits possible at higher latitudes, due to differing biophysical and socioeconomic conditions.
- Technological, economic, and policy developments play important roles in the global food system. In the near term to mid-century, these factors are likely to be at least as important to food security as climate change for most emissions scenarios; under high emissions and later in the century, climate effects become much larger.

Previous chapters have described projections of climate and societal change and interactions of climate change and various elements of food security. Those chapters show that the global food system links farm-production systems to consumers globally through a web of interconnected food systems. In this chapter, we first discuss the quantitative models that are being used to project how climate change may affect regional and global food systems and thus food security. We then discuss agriculture-specific scenarios that are used to implement impact assessments and review some of the pathways and scenarios that have been developed.

4.1 Impact-Assessment Framework for Agricultural and Food Systems

Climate and adaptation analyses found in the literature can be described as answering three sets of questions about climate change: (1) What effects would a change in climate today have on the current food system? (2) What effects would a change in climate have on the food system in the future, *without* adaptation to any changes in climate? Who would be most vulnerable to climate change without adaptation, and who might benefit from climate change? (3) How could the food system perform in the future with climate change *and* adaptation? How would adaptation reduce vulnerabilities and help exploit any benefits of climate change? As previously discussed, studies addressing the first question can help to characterize current sensitivity and vulnerability but are of limited use in assessing future climate-change effects. We therefore focus most of the following discussion on studies addressing the latter questions.

Various models have been used to address these questions about possible climate impacts and adaptation. Most studies have utilized the modeling structure shown in Figure 4.1, in which climate projections from general circulation models (GCMs) are used by biophysical models to simulate productivity effects of climate change. These productivity impacts are then used as inputs to economic models that simulate economic outcomes. Some economic models directly incorporate climate variables, thus bypassing the biophysical-simulation models. Each of the model components in Figure 4.1 is implemented using corresponding pathways and scenarios that define inputs into the models. These pathways and scenarios represent the key nonclimate future conditions projected to exist in the future period represented for the impact assessment, such as those described in Chapters 2 and 3 (e.g., technological change, population growth, and income growth). These factors define the socioeconomic setting in which the analysis is couched and thus can strongly influence the outcomes of the analysis.

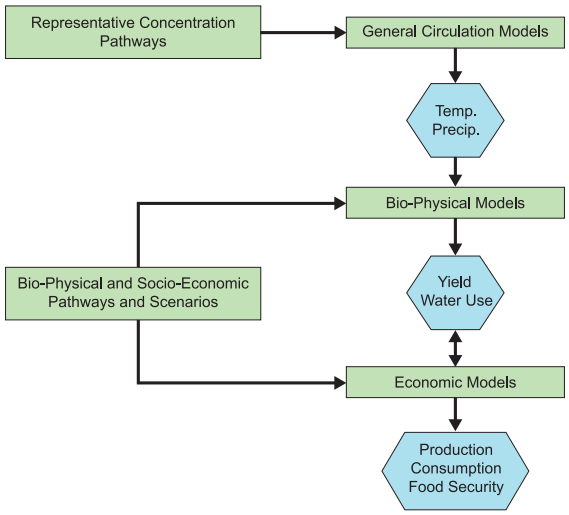

Figure 4.1 Framework for integrated agricultural and food system impact assessments. *Models of global economic and biophysical systems, driven by climate model outputs for different RCPs, are linked to assess outcomes under different future scenarios. Adapted from Wallach et al. 2015.*

The general modeling structure illustrated in Figure 4.1 can be elaborated in various ways, and the analysis can be carried out at various spatial and temporal scales. While in principle one large, fully integrated model could be constructed that would incorporate a dynamic system of nested biophysical and socioeconomic processes at different spatial and temporal scales, no such "supermodel" is currently feasible given data and computational limitations. Instead, a number of different models representing biophysical processes (e.g., crop growth) and economic processes (e.g., market determination of prices, production, consumption, and trade) are linked and simulated sequentially by passing outputs from one model to be used as inputs into another model in a logical sequence.

Global modeling systems generate outcomes such as food production and consumption at the national level or in multi-country regions and are thus relevant to food availability at those scales. To achieve higher analytical resolution for outcomes such as poverty and food security, several approaches have been developed. One approach is to link a global model to nationally disaggregated data (Hertel et al. 2010). Alternatively, the Agricultural Model Intercomparison and Improvement Project (AgMIP) has developed a coordinated global and regional approach to integrated assessment of agricultural effects and adaptation to address the three sets of questions identified earlier (Antle et al. 2015, Rosenzweig et al. 2013). In this approach (Figure 4.2), climate projections of temperature and precipitation from GCMs are downscaled and linked to globally gridded biophysical models that simulate productivity effects on crops and livestock. In addition, global socioeconomic pathways and scenarios are used to construct projections of other inputs needed for global agricultural economic models, such as productivity growth and trade policy. These global models simulate production, consumption, trade, and land use for multinational or national regions as well as market equilibrium prices. To obtain estimates of effects that are less highly aggregated (for example, specific to geographic regions or socioeconomic groups), the prices and yields from the global economic models are used as inputs into regional economic models. These regional models can simulate outcomes such as the regional distribution of production, income, and poverty rates and can be used to construct food-security indicators (see section 4.6.2).

4.2 Biophysical Models

The biophysical component of the assessment framework shown in Figure 4.1 can involve several parts. First, regional climate models or downscaling of gridded GCM outputs to higher spatial and temporal resolutions are needed to serve as inputs to global gridded production-system models and regional gridded or point-based models. These biophysical models should, in principle, represent major agricultural products, including crops and livestock, although thus far, most models have represented only major grain commodities (such as maize, soybeans, wheat, and rice), and some kinds of livestock. In addition, other components may represent water quantity, for example, by linking an economic model such as IMPACT to a watershed model (Rosegrant et al. 2012). Similar model linkages may be done with national or subnational models.

Biophysical crop and livestock models are important tools to use in translating the biophysical consequences of climate change (i.e., changes in temperature and precipitation) into yield changes that give rise to economic impacts. The findings of a large number of such crop model simulation studies is summarized in a recent meta-analysis that utilized over 1,700 studies of climate impacts on crop yields (Challinor et al. 2014) and in the latest assessment report of the IPCC (Porter et al. 2014). Challinor et al. (2014) found that without adaptation, losses in aggregate production of about 2%–10% are expected for wheat, rice, and maize in both temperate and tropical regions for a temperature increase of 2 °C over late 20th century temperatures. Crop-level

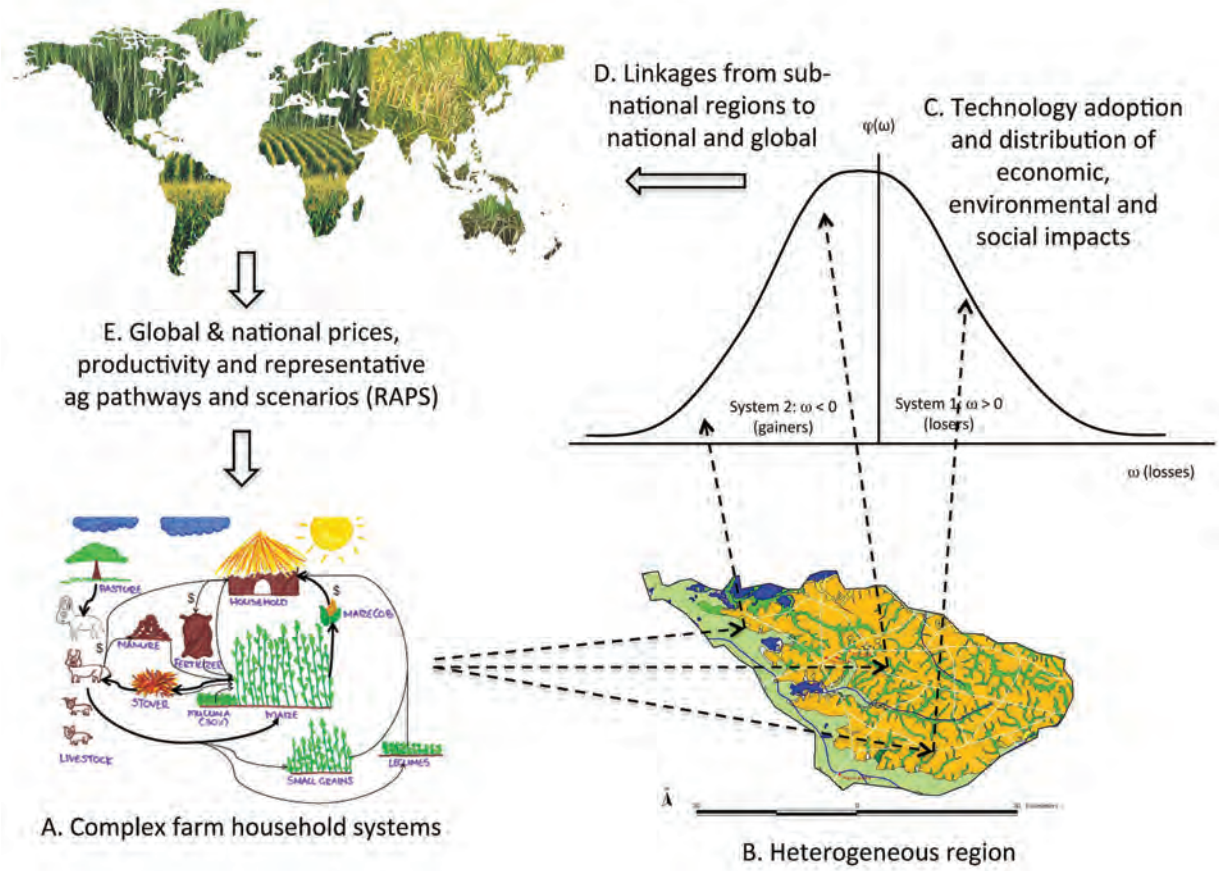

Figure 4.2 The AgMIP Regional Integrated Assessment Framework. *Climate-change impacts, adaptation, and vulnerability assessments are linked across scales, from the field and farm scale (A) to the landscape/subcountry scale (B), leading to analysis of technology adoption and impact assessment in heterogeneous farm household populations (C). This regional analysis may feed back to the country and global scales (D). The entire analysis uses consistent inputs and assumptions from global and national price and productivity projections and representative agricultural pathways (E). Source: Antle et al. 2015.*

adaptations increase simulated yields by an average of 7%–15% compared to yields modeled without adaptation, with adaptations more effective for wheat and rice than maize, again for a temperature increase of 2 °C over late 20th century temperatures. Yield losses were found to be greater in magnitude for the second half of the century than for the first. Consensus on yield decreases in the second half of the century is stronger for tropical than temperate regions, yet even moderate warming may reduce temperate crop yields in many locations.

When set up to operate on a spatial grid corresponding to climate data, crop and livestock models provide the expected changes in yield associated with downscaled future climate data generated from the GCMs (Jones and Thornton 2013). In recent model comparisons (Rosenzweig et al. 2014, Warszawski et al. 2014), three broad types of crop models were identified: (1) site-based crop models, (2) agro-ecological models, and (3) agro-ecological zone models. While differences in model types stem from the original purpose, scale, and parameterization of the models, the suite of models analyzed showed similarities in how they respond to changes in climate. These recent studies also indicate detrimental effects of climate change, especially at higher levels of warming and at low latitudes. Models that include explicit nitrogen stress project more severe impacts (see Figure 4.3 for the case of maize). Across seven global gridded crop models (GGCMs), five GCMs, and four representative concentration pathways, model agreement on the direction of yield changes is found in many major agricultural regions at both low and high latitudes. However, better understanding of yield response to factors such as atmospheric carbon dioxide (CO_2 fertilization), nitrogen applications, and high temperatures is needed to improve confidence in impact assessments and to evaluate adaptation strategies.

There are also important limitations to these models that are the subject of ongoing research and model improvements (Bryan et al. 2009, Mertz et al. 2010). For example, crop-simulation models can represent only some aspects of adaptation, such as changes in

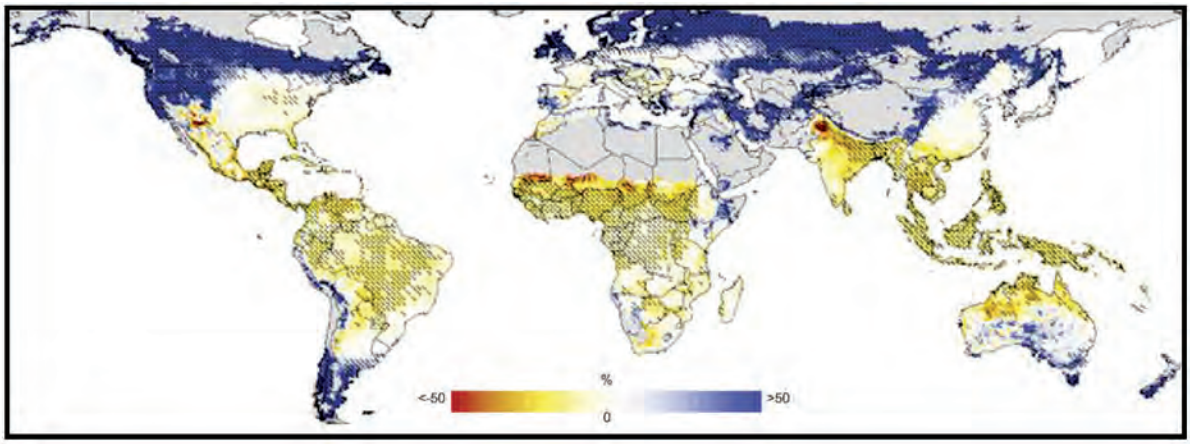

Figure 4.3 Median yield changes for RCP 8.5 (2070–2099) relative to 1980–2010. *Analysis includes CO_2 effects over five GCMs X seven GGCMs for rain-fed maize. Hatching indicates areas where more than 70% of the ensemble members agree on the directionality of the yield change. Gray areas indicate historical areas with little to no yield capacity. Source: Rosenzweig et al. 2014.*

cultivars, planting dates, and the use of irrigation. Another important limitation is that most models do not explicitly account for pests and diseases. Crop models also have difficulty predicting response of yields to the timing of rainfall and dry spells within a growing season (Baigorria et al. 2007, Lobell 2013, Ramirez-Villegas and Challinor 2012). Despite these issues, biophysical models are providing useful insights into potential effects of climate change on crop growth and yield.

4.3 Global Economic Models

Two types of economic models have been used for global assessments of climate impacts: (1) Partial Equilibrium (PE) models and (2) Computable General Equilibrium (CGE) models (Burfisher 2011). PE models represent one or a few sectors of the economy, whereas CGE models represent the entire economy, including linkages between sectors (manufacturing, agricultural, service, etc.) used to produce economy-wide final outputs (van der Mensbrugghe 2013). Both types of models use a set of mathematical equations to represent the economy, utilize databases of information that quantify economic activity of firms and consumers, and use assumptions that are often based on empirical literature to create initial input values (van Tongeren et al. 2001). PE models typically provide a more-detailed representation of the agricultural sector, but a less-complete representation of the entire economy, than CGE models.

These models are useful because they can simulate policy "experiments" before policies are implemented, making it possible to investigate possible future impacts of technological and climate changes and adaptations (Hertel et al. 2010, Lofgren et al. 2002). However, as discussed in the next section, the various models in the literature can produce substantially different projections of economic outcomes, suggesting substantial model uncertainty.

4.4 Regional Economic Impact-Assessment Models

There are various types of economic models that can be used for regional impact assessment, including regional optimization models (e.g., Mérel and Howitt 2014), regional technology-adoption and impact-assessment models (e.g., Antle 2011, Claessens et al. 2012), regional land-use models (Wu et al. 2004), and national partial-equilibrium economic models (Beach et al. 2010). Also, various statistical and econometric models have been used to assess climate-change impacts on economic outcomes, such as land values or value of production (e.g., Mendelsohn and Dinar 2009).

Some regional models are focused on commodities, while other models represent the linkages among crop- and livestock-production systems. Some models also include representation of household activities such as food preparation and nonagricultural income-generating activities such as off-farm work. These models utilize variables from global models as inputs—notably prices, productivity, and land use. However, the global models do not project the level of detail needed for a number of important input variables (for example, farm size, household size, the use of family

and hired labor, and cost of production), so these input variables must be set by the researcher to be consistent with the future socioeconomic scenarios used in the analysis. Like global models, these regional models can be linked to biophysical crop and livestock production models to incorporate the effects of climate change on productivity. Van Wijk et al. (2014) reviewed 126 farm-level and regional models and found that none of them had been formulated to directly model food-security outcomes, but they did simulate food-production and income outcomes that are related to food availability and access.

4.5 Global Climate-Impact Assessments for Agricultural Systems

Most global agricultural assessments carried out over the past decade have utilized scenarios from the IPCC Special Report on Emissions Scenarios together with corresponding data from the CMIP. Some studies utilized "business as usual" trends, whereas others used scenarios with a range of alternate plausible futures. The latter studies include the recently updated FAO World Agriculture Towards 2030/2050 projections (Alexandratos and Bruinsma 2012), the reference-world scenario of the International Assessment of Agricultural Science and Technology for Development (IAASTD 2009), and the baseline scenarios of the IFPRI Food Security, Farming, and Climate Change to 2050 report (Nelson et al. 2010).

4.5.1 Global Assessment Pathways and Scenarios for Agriculture

In collaboration with AgMIP and the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (Warszawski et al. 2014), a group of nine major modeling teams completed the first global agricultural economic model intercomparison of climate change impacts, in which all of the models used a standard set of scenarios that combined RCP 8.5 with the population- and economic-growth assumptions from two SSPs, two crop-simulation models to project the impacts of climate change on crop productivity, two biofuel-policy assumptions, and one scenario with a lower price of oil (Nelson and van der Mensbrugghe et al. 2014, von Lampe et al. 2014). The goal of the model-comparison exercise was to understand the differences in model projections and behavior and to identify the sources of these differences. The group did use a consistent set of assumptions for key driver variables, including assumptions for crop yields, energy-price (based on crude-oil price), and the production of biomass-based energy. Importantly, these scenarios did not embody the effects of increasing CO_2 concentrations, such as increased CO_2 fertilization, on crop yields and used climate projections based on RCP 8.5, so in these dimensions the scenarios can be viewed as relatively pessimistic. However, the group did incorporate a relatively optimistic set of projected growth rates for crop yields to represent the impacts of ongoing productivity improvements. These rates ranged from 1% to 2.5% for major crops (wheat, coarse grains, rice, sugar, and oilseed) across the major regions of the world (von Lampe et al. 2014), so in this regard the scenarios can be viewed as somewhat optimistic.

To increase the relevance of socioeconomic pathways to agriculture, AgMIP has developed the concept of *representative agricultural pathways* (RAPs) for both global and regional impact assessment. RAPs are designed to be an internally consistent set of narratives and drivers for integrated assessment of climate impact, adaptation, and vulnerability that can be linked to SSPs (Valdivia et al. 2015). As an extension of the previously described AgMIP/ISI-MIP global model intercomparison that was carried out with nine models, five of those global modeling teams developed a set of RAPs corresponding to SSPs 1, 2, and 3 (refer to Chapter 3 for SSP definitions). In addition to the economic-growth, population-growth, urbanization, and land-use assumptions associated with the three SSPs, these RAPs involved a set of distinct agricultural assumptions for yield growth and agricultural trade policy. The first RAP was associated with SSP1 and RCP 4.5, and included both standard SSP1 trade-policy assumptions and a variation with liberalized agricultural trade; the second RAP was associated with SSP2 and RCP 6.0, with SSP2's neutral (business as usual) agricultural trade; and the third RAP was associated with SSP3 and RCP 8.5, including both the standard SSP3 trade policy and a variation with more-restrictive trade (Wiebe et al. 2015). Results from these RAPs are reported in section 4.5.3.

4.5.2 Global Economic Model Projections and Implications

Literature on assessing the impacts of climate change on projected global agricultural productivity and food security is vast. A recent summary is provided by the Commission on Sustainable Agriculture and Climate Change (Beddington et al. 2012, Porter et al. 2014, Hertel and Lobell 2014). Here we highlight some key findings of this summary and their implications for food security.

Early interdisciplinary studies combined partial- and general-equilibrium economic models, crop models, and climate models to make projections about future food supplies (Rosenzweig and Parry 1994, Rosenzweig and Iglesias 1994, Sonka and Lamb 1987). These studies projected that climate change would cause an increase in the total number of people at risk of hunger relative to a world without climate change, though that number would represent a lower proportion of the total population due to population growth over that time period (Chen and Kates 1994, Fischer et al. 1994, Fischer et al. 1996, Rosenzweig and Parry 1994). Subsequent studies refined projections but did not substantially alter the implications of the earlier studies; however, they did emphasize more-adverse effects on developing countries in the tropics (Fischer et al. 2005, Parry et al. 2005). These and more-recent studies also demonstrated the differences that technological improvements and overall income growth could make in reducing food insecurity and showed that those effects could be much more important than the effects of climate change up to mid-century (Nelson et al. 2009 and 2010, Porter et al. 2014). Thus, recent studies have shown that socioeconomic conditions play a major role in determining vulnerability to climate change.

Global modeling studies simulate global and regional food production, prices, consumption, and trade. To translate these effects into changes in food security, additional assumptions and analyses are required. One approach used by global modeling studies is to develop statistical links between projected changes in production or consumption to food-security indicators. For example, Fischer et al. (2005) utilized the correlation between the share of individuals undernourished (as defined by the Food and Agriculture Organization) in the population and the ratio of average national food supply (including imports), relative to aggregate national food requirements, to assess the impacts of climate change on food security. Based on this relationship (Figure 4.4), and using a set of socioeconomic and GHG-concentration scenarios based on the SRES, Fischer et al. found that the percentage of undernourished population approached zero in countries where food production exceeds 160% of national requirements.

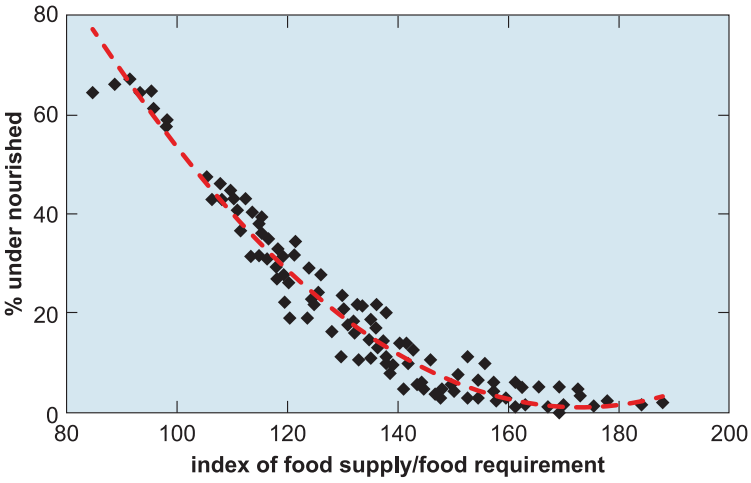

Figure 4.4 Estimates of undernourished population relative to food supply. *This relationship based on data from the Food and Agriculture Organization shows a correlation between the shares of undernourished individuals in the total population and the ratio of average national food supply, including imports, relative to aggregate national food requirements. Source: Fischer et al. 2005.*

Fischer et al. also projected that a scenario characterized by high GHG concentrations, high population growth rates, and constrained economic development (the SRES A2 scenario, roughly similar to SSP3) would increase the number of people at risk of hunger, finding that an additional 175 million people could be undernourished in 2080 because of climate change (representing 2.6% of the projected overall population of food-insecure countries in 2080). The same socioeconomic conditions in conjunction with CO_2 concentrations of about 550 ppm resulted in an estimate of up to 60 million additional people at risk; concentrations of about 350 ppm did not result in an increased number of people at risk. In the less-pessimistic SRES scenarios, declines in the risk of hunger over time due to socioeconomic change outweigh increase in hunger risk due to climate change. Analyses based on hypothetical scenarios of sustained economic growth and moderate population growth without climate change suggest that the number of food-insecure people could be reduced by 50% or more by 2040, with further reductions over the rest of the century. Such analyses should not be interpreted as projections, since climate change is already occurring, but they clearly indicate that socioeconomic factors have large effects on food insecurity.

Another example of an indicator used to examine economic outcomes on health and nutrition is found in a study by Nelson et al. (2010), which compared per-capita calorie availability from cereals and meat against an index of child malnutrition. For the former, the study used the IMPACT model, which estimates per-capita calorie availability by country. For the latter, the study estimated the percentage of malnourished children under the age of 5 using average per-capita calorie consumption, assuming that other important factors (life expectancy, maternal education, and clean-water access) are constant in all future scenarios. Estimates of calorie availability and child malnutrition were updated based on

hypothetical investments in agricultural research, roads and irrigation. The goal of the study was to estimate the agricultural-productivity growth needed to meet a nutrition or calorie-availability target and then estimate the investment expenditures needed in research, irrigation, and roads to generate that productivity growth. As with the Fischer et al. (2005) study, a major limitation of this methodology is that it relies on data aggregated to the national level (in this case, data for calorie availability) and thus cannot represent changes in food access, utilization, or stability among country populations.

Based on this methodology, Nelson et al. (2010) found that climate change and ongoing global development could contribute to price increases for the most important agricultural crops—rice, wheat, maize, and soybeans—and that higher feed prices result in higher meat prices. These researchers projected that these price increases would slightly reduce growth in meat consumption and cause a more substantial fall in cereal consumption. Projections that combined climate change and pessimistic socioeconomic conditions resulted in a decline in calorie availability in 2050 relative to 2000 levels throughout the developing world. By 2050, this decline in calorie availability could increase child undernutrition in low-income developing countries by 20% relative to a world with no climate change. More positive socioeconomic conditions resulted in less-negative effects but still produced less improvement than cases with no climate change. In conclusion, this study shows that climate change could reduce much of the improvement in child malnourishment levels that could occur without climate change.

4.5.3 AgMIP Global Integrated Modeling Results

Some key findings of the AgMIP global agricultural model intercomparisons and related climate-impact assessments, based on nine global economic models, are discussed below and summarized in Figures 4.5, 4.6, and 4.7 (Nelson and Valin et al. 2014, Nelson and van der Mensbrugghe et al. 2014, von Lampe et al. 2014, Wiebe et al. 2015). Figure 4.5 presents price projections for five agricultural-commodity groups (wheat, coarse grains, rice, oilseeds, and ruminant meat) for 2050. These projections exclude climate change but include other factors such as income growth, population growth, and trends in agricultural productivity. This figure is useful because it shows how differently the nine models perform in terms of projecting future economic outcomes such as prices. The figure shows that some models project substantially higher agricultural-commodity prices in the future relative to those observed today, whereas other models show prices falling. Therefore, even without imposing climate change on the agricultural economic models, a wide range of plausible future price trends are possible, suggesting that there is a high degree of uncertainty in these model projections that is distinct from uncertainty associated with the introduction of climate-change effects.

Figure 4.6 summarizes the projected results for the impacts of climate change, using the nine global

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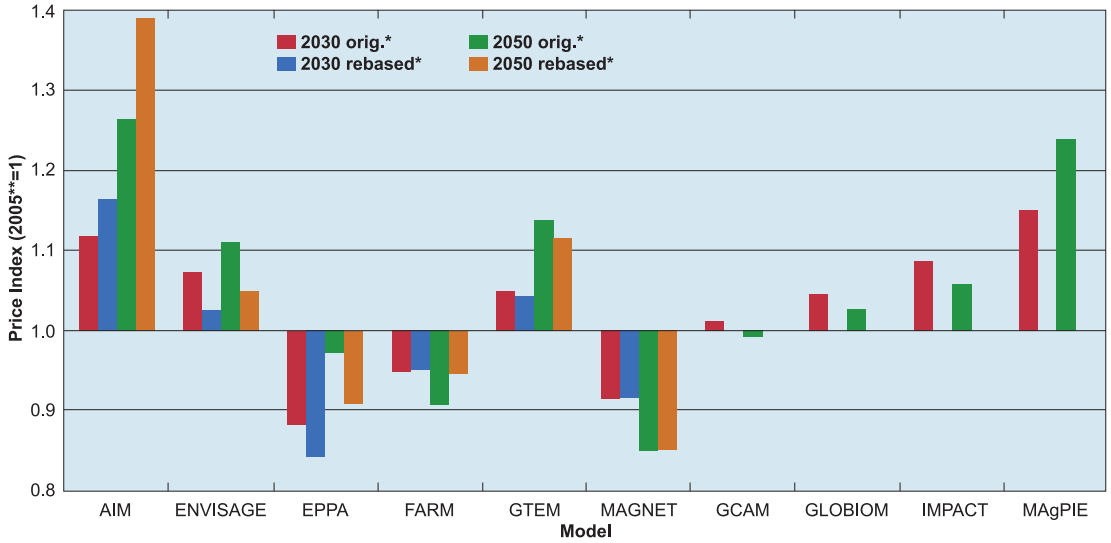

* original: relative to model-standard numeraire; rebased; relative to the price index for the global GDP
** trended 2005, i.e. hypothetical in the absence of short-term shocks

Figure 4.5 Projected changes in commodity prices in 2050, absent climate change. *This aggregate index for wheat, coarse grains, rice, oilseeds, and sugar shows the differences in price projections across global agricultural economic models when socioeconomic changes such as population growth and economic growth are included and climate change is not. Source: von Lampe et al. 2014.*

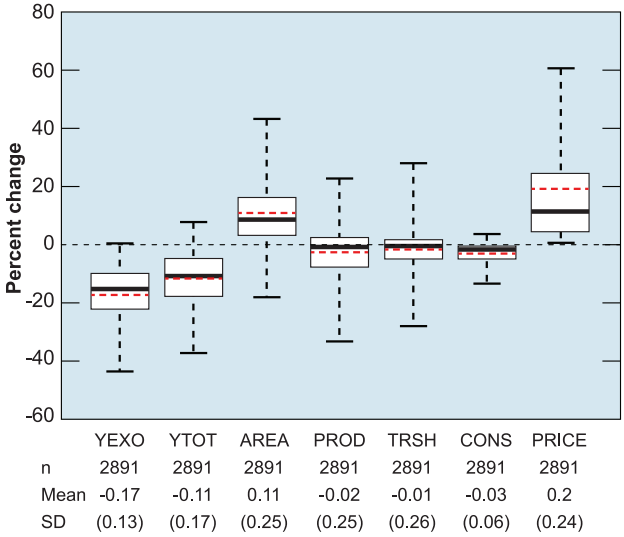

Figure 4.6 Change and variability of crop and economic model projections for 2050. *In 2050, lower average yields under climate change, either with (YTOT) or without (YEXO) climate adaptation management measures, result in higher prices (PRICE) for most agricultural commodities, in spite of increased land area under production (AREA). Adaptation measures reduce climate impacts on yields (YEXO vs. YTOT), while global production (PROD), consumption (CONS), and trade (TRSH) are not projected to dramatically change. Significant variability results from the study spanning nine models, four crop aggregates, seven crop models and socioeconomic scenarios, and 13 regions. Source: Nelson and Valin et al. 2014.*

economic models in the AgMIP study. This figure shows results from seven different socioeconomic scenarios that included two SSPs, two different crop models to project effects of climate change on productivity, and alternative assumptions about the prices of biofuels and fossil fuels. Several important points can be observed from the different columns presented within the figure. The lower average yields associated with climate change in most parts of the world are reflected in higher prices for most agricultural commodities compared to a world with a 2005 climate, but the size of this effect varies widely across the models, ranging from 0% to 20% for most models. Global consumption in 2050, however, is not expected to decline significantly relative to the baseline scenario without climate change. Most models project some increases in land area under production but with little impact on trade relative to a world without climate change in 2050.

An important question for the U.S. food system is how these global projections for production, consumption, trade, and prices compare to impacts on the United States. When the results of the global models are disaggregated by major regions of the world, the results show substantially the same patterns as Figure 4.6, even though the impacts of climate change on crop and livestock productivity is projected

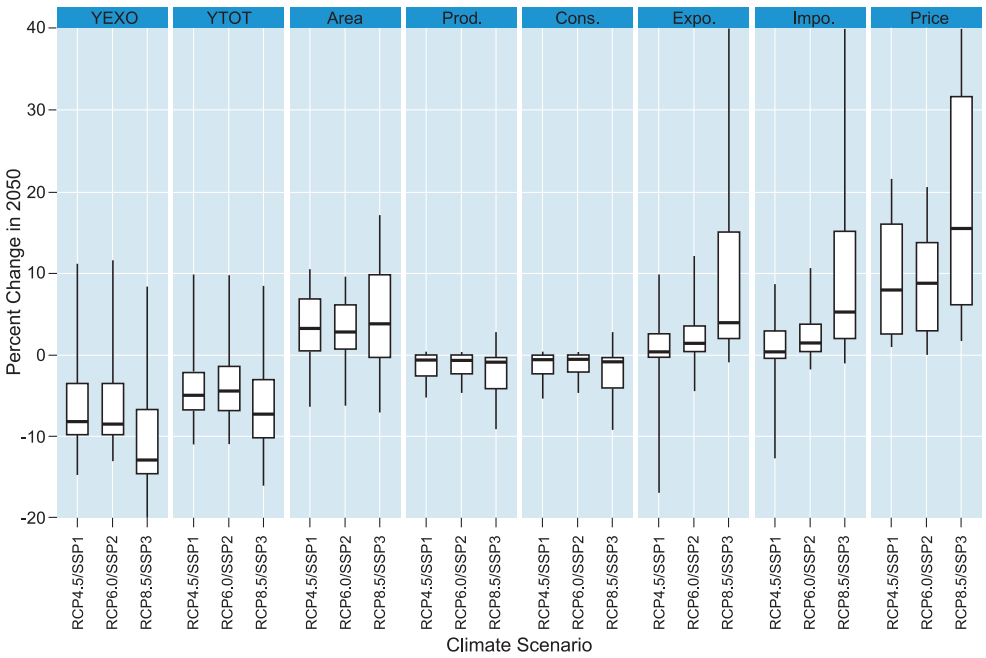

Figure 4.7 Climate-change effects under different SSPs and RCPs. *The "high-concentration/low-international cooperation" scenario (RCP 8.5/SSP3) shows much larger and more variable climate-change effects for the five commodities (coarse grains, rice, wheat, oilseeds, and sugar), with a more pessimistic development pathway, than the "medium-concentration/middle-of-the-road" (RCP 6.0/SSP2) and "low-concentration/sustainable-development" (RCP 4.5/SSP1) scenarios. Results are from three GCMs and five economic models, aggregated across 13 regions (n = 75). YEXO = yield effect of climate change without technical or economic adaptation, YTOT = realized yields after adaptation, AREA = agricultural area in production, PROD = total production, CONS = consumption, Expo = exports, IMPO = imports, PRICE = prices. Source: Adapted from Wiebe et al. 2015.*

to be larger for regions such as Africa and South Asia. These findings suggest that with largely integrated global markets and relatively free trade, the impacts of climate change are likely to be distributed around the world through the offsetting effects of the market and other economic adjustments.

As noted previously, the AgMIP global model intercomparison using nine models was extended to an analysis of RAPs that were designed to be consistent with three SSPs, each combined with a different assumed climate outcome (Wiebe et al. 2015): SSP1 with a medium level of climate change (RCP 4.5), SSP2 with somewhat more climate change (RCP 6.0), and SSP3 with a high level of climate change (RCP 8.5). Figure 4.7 summarizes the results of these projections for aggregate yield, area, production, consumption, trade and prices from five economic models. The results show that there are substantial differences between the "high-concentration, high-population growth, restrained-economic growth" scenario (SSP3/RCP 8.5) and the "low-concentration, low-population growth, high-economic growth" and "medium-concentration, medium-population growth, high-economic growth" scenarios (SSP1/RCP 4.5 and SSP2/RCP 6.0). The high-concentration, high-population, lower-economic growth scenario shows much larger climate-change effects than the lower-concentration scenarios, and also much larger differences across the models.

Wiebe et al. (2015) project that yields would decline by a median of 7.2% in the high-concentration scenario, while area would increase by 3.8%, production and consumption would decline by 0.9%, exports and imports would increase by 4.0% and 5.3% (respectively), and prices would increase by 15.5%, all relative to a baseline projection for 2050 that does not include additional climate change between now and then. They also found that this scenario produced a wider range of price effects across crops and models than the two lower-emissions scenarios. Further analysis of the baseline scenarios suggests that the climate effects in 2050 of a high-emissions scenario are stronger than the differences between the underlying socioeconomic trends, at least at the global level.

Wiebe et al. (2015) also show that in the case of low international cooperation and high concentrations (SSP3/RCP 8.5), restricting trade results in higher prices, and thus more-adverse consequences of climate change, and a larger spread across models. This result is what economists would expect and shows that trade policy and other aspects of economic and political coordination are likely to play a role in determining the impacts of climate change on global and regional food security. However, it is important to note that the differences across scenarios cannot be attributed to any single factor, as both climate and socioeconomic conditions change.

4.6 Regional Modeling Studies

A number of regional (national or subnational) modeling studies have assessed the effects of climate on agriculture (Porter et al. 2014). These regional studies include statistical and process-based studies of crop productivity, similar to the GGCM studies discussed previously; regional econometric studies that focus on predicting how climate change may affect economic outcomes such as crop revenue or land values; and regional integrated-assessment studies, similar in design to the global modeling studies described earlier but focused on national or subnational regions.

4.6.1 Statistical, Econometric, and Integrated-Assessment Studies

Schlenker and Lobell (2010) used statistical models to evaluate the potential effects of climate change on crops in Africa. They combined historical crop-production and weather data into a model of yield response to climate change for several key African crops. By mid-century, the mean estimates of aggregate production changes in Sub-Saharan Africa are estimated to be −22% for maize, −17% for sorghum, −17% for millet, −18% for groundnut, and −8% for cassava, compared to a historical baseline period of 1961–2000. They also found that countries in this region with the highest average yields had the largest projected yield losses, suggesting that well-fertilized modern seed varieties are more susceptible to heat-related losses.

The high-concentration, high population, lower economic growth scenario shows much larger climate change effects than the lower concentration scenarios

Econometric models have also been used to assess climate impacts on economic outcomes such as farmland values and revenues. A study by Mendelsohn and Dinar (2009) on a number of regions of the world suggest that agriculture in developing countries is more sensitive to changes in climate than agriculture in developed countries. This is consistent with the generally more-adverse effects of climate change on crop and livestock productivity in the tropics found in crop- and livestock-modeling studies. Rain-fed cropland is generally more sensitive to warming than irrigated cropland (Mendelsohn and Dinar 2009). The analysis shows that farmers are likely to make many adjustments to adapt to climate change, including switching crops and livestock species, modifying irrigation practices,

and alternating between livestock and crops. The results also reveal that effects and adaptations vary across landscapes, suggesting that adaptation policies must be location-specific. However, the focus of these studies on outcomes such as crop yields and farm revenues limit their ability to provide direct information and assessment of food-security outcomes.

Recent studies by Valdivia et al. (2012) and Claessens et al. (2012) illustrate the use of a disaggregated regional integrated-assessment approach and were the first regional studies to utilize RAPs to project impacts under future socioeconomic conditions. These studies assessed the effects and possible adaptation strategies on the incomes and poverty of farm households in two regions of Kenya. The studies showed that the adverse impacts of climate change could be largely offset by feasible adaptations involving new crops and intensification of livestock production. Like some of the global studies, these studies also demonstrated the important role that future socioeconomic conditions are likely to play in determining vulnerability to climate change and the value of adaptation. While these studies did assess the distributional effects of climate change on income and poverty, they did not directly incorporate all of the factors, such as regional food availability, utilization, and stability, that would be needed to assess climate-change effects and adaptations for food security.

4.6.2 Regional AgMIP Studies of Africa and South Asia

Regional assessments of climate-change effects in Africa and South Asia, currently two of the world's most food-insecure regions, have been conducted according to the methodology provided in Figure 4.2 and are summarized in Figure 4.8 (Rosenzweig and Hillel 2015, Valdivia et al. 2015). These assessments were carried out by regional teams that devised a RAP for each of the regions corresponding to the middle-of-the-road global socioeconomic scenario SSP2 (Valdivia et al. 2015). Climate change was represented by five GCMs selected to span the range of climate uncertainty in the IPCC CMIP5 data with RCP 8.5. The RAPs were generally optimistic, being based on the positive trends in productivity growth that were assumed in the AgMIP global model intercomparison study, as well as positive trends in agricultural prices due to increasing global food demand projected by the IFPRI IMPACT model. The variation in each indicator shown in Figures 4.7 and 4.8 is due to the variation in climate projections as well as regional differences in biophysical and socioeconomic conditions across the various study sites. Preliminary analysis of adaptation strategies is reported in Rosenzweig and Hillel (2015) but is not included in Figure 4.8.

The AgMIP regional studies produced indicators of (a) vulnerability (defined as the number of farm households that lose income due to climate change), (b) impacts on average (or net) per-capita income, and (c) changes in poverty; however, they did not include food-security indicators. Figure 4.8 demonstrates that there is a wide range of vulnerability to climate change under current socioeconomic conditions, averaging about 70% across study sites. The figure also shows that under the generally more-favorable future socioeconomic conditions defined by the regional RAPs, vulnerability to climate change averages less than 50%, demonstrating that positive socioeconomic developments could increase farm incomes and, in some cases, help to reduce vulnerability to climate change and to reduce poverty.

These studies have several important implications regarding the potential effects of climate change on the well-being of agricultural households. First, even in highly vulnerable regions, there is a range of household-level outcomes, with some households expected to lose and some to gain from climate change acting within the context of other socioeconomic changes. Second, preliminary analysis by the regional teams of possible adaptations of current systems shows that there are substantial opportunities to offset the adverse impacts and enhance the beneficial effects of climate change. Third, like other global and regional studies, these regional studies show the important role that socioeconomic conditions will play in determining vulnerability, impact, and adaptation potential.

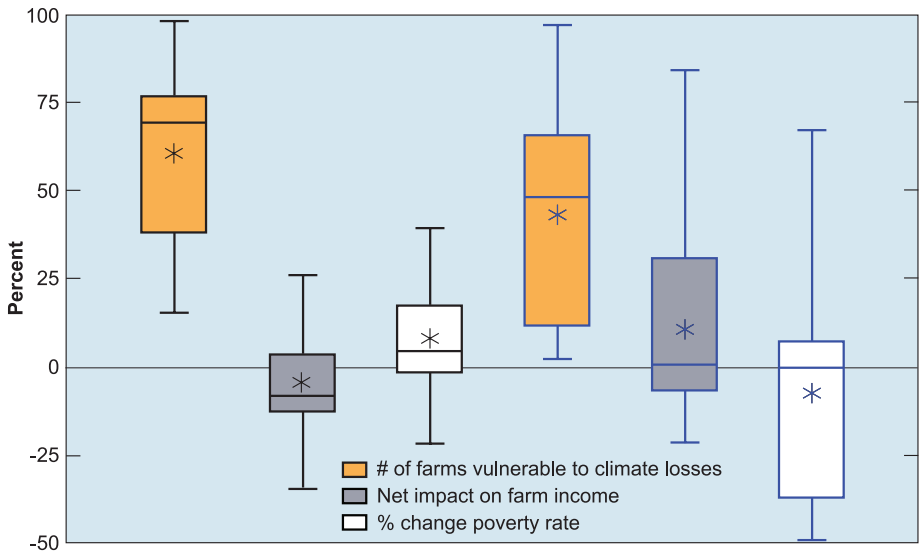

Figure 4.8 Summary of regional studies of climate-change impacts in West, East, and Southern Africa and South Asia under current and future socioeconomic conditions. *Adaptation is not considered in this figure. Bars show the range of outcomes from five climate scenarios, two crop models, and one socioeconomic scenario (current and future) for various study areas in Africa and South Asia; boxes indicate quartiles; asterisks are averages. Boxes outlined in black (left side) indicate current socioeconomic conditions; boxes outlined in blue (right side) indicate socioeconomic conditions in mid-century based on "middle-of-the-road" SSP2 and corresponding regional RAPs. Source: Wiebe et al. 2015.*

4.7 Conclusions

Climate-change effects on overall global food production are likely to be detrimental, particularly later in the century, but vary substantially by region. The most adverse effects are likely to be in the tropics and subtropics, and some benefits are possible at higher latitudes. Effective adaptation can help to offset climate-change effects. Detailed regional studies show that the regional differences in effects can be large, due to differing biophysical and socioeconomic conditions that determine both the effects of climate change and the potential for beneficial adaptation.

Global-scale food-system models can be used to assess climate-change effects on global and national food availability, but data are too aggregated to assess all of the important food-security concerns related to access, utilization, and stability. More detailed data and models and additional model intercomparisons are needed to assess climate-change effects on all dimensions of food security at subnational, local, and household levels.

Substantial differences in projections of price, production, and land-use changes by different models exist, implying a high degree of model uncertainty in impact projections. In addition to reducing these uncertainties, needed model improvements include a more-complete representation of risks to food production from pests and diseases and a more-complete and detailed representation of the food system beyond the farm gate, including food transportation, storage, processing, and distribution, and other parts of the comprehensive food system.

Technological, economic, and policy considerations also play a role in the global food system and future global food security, demonstrating that climate assessments need to be made in the context of plausible future socioeconomic scenarios. Many studies indicate that these technological and socioeconomic factors are likely to be at least as important to food security as climate change under low-to-medium emissions and concentration scenarios in the near term to mid-century. Under higher emissions scenarios and over the longer term, climate effects are projected to be equal to or greater than the effects of socioeconomic change.

Many studies indicate that these technological and socioeconomic factors are likely to be at least as important to food security as climate change under low-to-medium emissions and concentration scenarios in the near term to mid-century.