Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. National research Council 2010

5.1 FOOD PRODUCTION, PRICES, AND HUNGER

Even in the most highly mechanized agricultural systems, food production is very dependent on weather. Concern about the potential impacts of climate change on food production, and associated effects on food prices and hunger, have existed since the earliest days of climate change research. Although there is still much to learn, several important findings have emerged from more than three decades of research.

It is clear, for example, that higher CO2 levels are beneficial for many crop and forage yields, for two reasons. In species with a C3 photosynthetic pathway, including rice and wheat, higher CO2 directly stimulates photosynthetic rates, although this mechanism does not affect C4 crops like maize.

Secondly, higher CO2 allows leaf pores, called stomata, to shrink, which results in reduced water stress for all crops. The net effect on yields for C3 crops has been measured as an average increase of 14% for 580 ppm relative to 370 ppm (Ainsworth et al., 2008).

For C4 species such as maize and sorghum, very few experiments have been conducted but the observed effect is much smaller and often statistically insignificant (Leakey, 2009).

Rivaling the direct CO2 effects are the impacts of climate changes caused by CO2, in particular changes in air temperature and available soil moisture. Many mechanisms of temperature response have been identified, with the relative importance of different mechanisms varying by location, season, and crop.

Among the most critical responses are that crops develop more quickly under warmer temperatures, leading to shorter growing periods and lower yields, and that higher temperatures drive faster evaporation of water from soils and transpiration of water from crops. Exposure to extremely high temperatures (e.g., > 35°C) can also cause damage in photosynthetic, reproductive, and other cells, and recent evidence suggests that even short exposures to high temperatures can be crucial for final yield (Schlenker and Roberts, 2009; Wassmann et al., 2009).

A wide variety of approaches have been used in an attempt to quantify yield losses for different climate scenarios. Some models represent individual processes in detail, while others rely on statistical models that, in theory, should capture all relevant processes that have influenced historical variations in crop production. Figure 5.1 shows model estimates of the combined effect of warming and CO2 on yields for different levels of global temperature rise. It is noteworthy that although yields respond nonlinearly to temperature on a daily time scale, with extremely hot days or cold nights weighing heavily in final yields, the simulated response to seasonal warming is fairly linear at broad scales (Lobell and Field, 2007; Schlenker and Roberts, 2009). Several major crops and regions reveal consistently negative temperature sensitivities, with between 5-10% yield loss per degree warming estimated both by process-based and statistical approaches.

Most of the nonlinearity in Figure 5.1 reflects the fact that CO2 benefits for yield saturate at higher CO2 levels.

For C3 crops, the negative effects of warming are often balanced by positive CO2 effects up to 2-3°C local warming in temperate regions, after which negative warming effects dominate. Because temperate land areas will warm faster than the global average (see Section 4.2), this corresponds to roughly 1.25-2°C in global average temperature. For C4 crops, even modest amounts of warming are detrimental in major growing regions given the small response to CO2 (see Box 5.1 for discussion of maize in the United States).

Figure 5.1

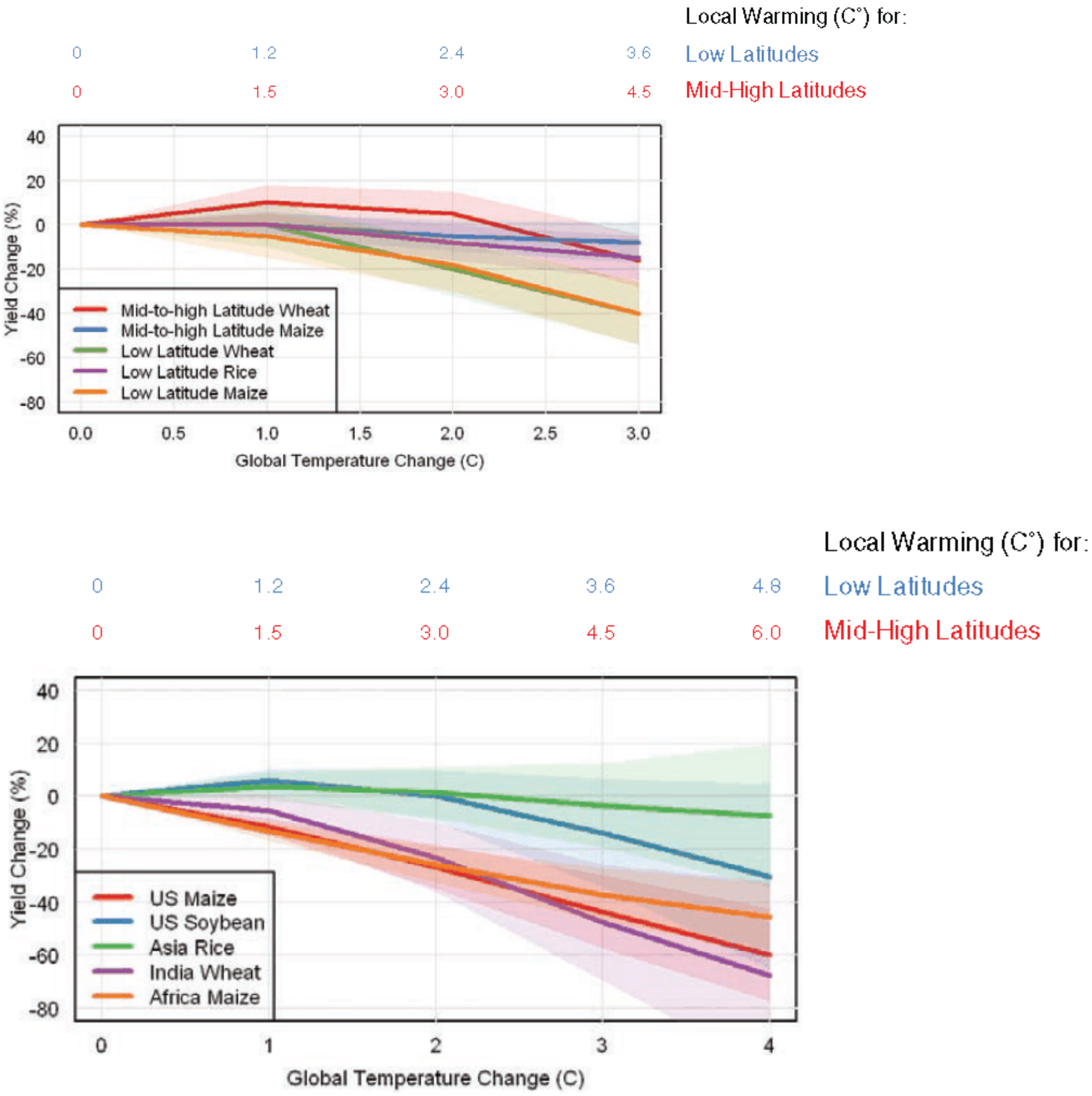

FIGURE 5.1 Average expected impact of warming + CO_2 increase on crop yields, without adaptation, for broad regions summarized in IPCC AR4 (left) and for selected crops and regions with detailed studies (right). Shaded area shows likely range (67%). Impacts are averages for current growing areas within each region and may be higher or lower for individual locations within regions. Temperature and CO_2 changes for the IPCC summary (left) are relative to late 20th century, while changes estimated for regions (right) were computed relative to pre-industrial. Estimates were derived from various sources (Matthews et al., 1995; Lal et al., 1998; Easterling et al., 2007; Schlenker and Roberts, 2009; Schlenker and Lobell, 2010) (see methods in Appendix for details).

BOX 5.1 HOW WILL MAIZE YIELDS IN THE UNITED STATES RESPOND TO CLIMATE CHANGES?

Nearly 40% of global maize (or corn) production occurs in the United States, much of which is exported to other nations. The future yield of U.S. maize is therefore important for nearly all aspects of domestic and international agriculture. Higher temperatures speed development of maize, increase soil evaporation rates, and above 35°C can compromise pollen viability, all of which reduce final yields. High temperatures and low soil moisture during the flowering stage are especially harmful as they can inhibit successful formation of kernels. In northern states, warmer years generally improve yields as they extend the frost-free growing season and bring temperature closer to optimum levels for photosynthesis. The majority of production, however, occurs in areas where yields are favored by cooler than normal years, so that warming associated with climate change would lower average national yields. The most robust studies, based on analysis of thousands of weather station and harvest statistics for rainfed maize (>80%

of U.S. production), suggest a roughly 7% yield loss per °C of local warming, which is in line with previous estimates (USCCSP, 2008b). Given the rate of local warming in the Corn Belt relative to global average, this implies an 11% yield loss per °C of global warming (Figure 5.1).

Whether these losses are realized will depend in large part on the effectiveness of adaptation strategies, which include shifts in sowing dates, switches to longer maturing varieties, and development of new seeds that can better withstand water and heat stress and better utilize elevated CO_2. A wide range of maize varieties are currently sown throughout the country, customized to local factors such as latitude, growing season length, and soil, and new varieties are continually developed by private seed companies. These companies have historically focused on biotic stresses, but are now releasing the first varieties explicitly targeted for drought resistance.

Heat tolerance has not received much investment outside of drought-related traits, likely because of limited economic incentives in current climate. A comparison of maize yields in northern and southern states suggests minimal historical adaptation to heat, as varieties that are more frequently exposed to temperatures above 30°C exhibit similar sensitivities to varieties grown in the North (Schlenker and Roberts, 2009). A major challenge in developing drought and heat tolerance is that traits that confer these often reduce yields in good years, and growers and seed companies have little economic incentive to accept this trade-off given current markets and insurance programs. Another persistent challenge is the decade or more lag between initial investments and seed release. In short, adaptation could offer large benefits, but only if formidable technical and institutional barriers are overcome. To put the challenge in context, global cereal demand is expected to rise by roughly 1.2% per year (FAO, 2006), so that adapting to 1°C global warming (or avoiding 11% yield loss) is equivalent to keeping pace with roughly 9 years of demand growth. The corresponding expected impact of 2°C global warming is 25%, or roughly 20 years of demand growth.

The expected impacts illustrated in Figure 5.1 are useful as a measure of the likely direction and magnitude of average yield changes, but fall short of a complete risk analysis, which would, for instance, estimate the chance of exceeding critical thresholds. The existing literature identifies several prominent sources of uncertainty, including those related to the magnitude of local warming per degree global temperature increase, the sensitivity of crop yields to temperature, the CO2 levels corresponding to each temperature level (see Section 3.2), and the magnitude of CO2 fertilization. The impacts of rainfall changes can also be important at local and regional scales, although at broad scales the modeled impacts are most often dictated by temperature and CO2 because simulated rainfall changes are relatively small (Lobell and Burke, 2008).

In addition, although the studies summarized in Figure 5.1 consider several of the main processes that determine yield response to weather, several other processes have not been adequately quantified. These include responses of weeds, insects, and pathogens; changes in water resources available for irrigation; effects of changes in surface ozone levels; effects of development of new seeds that can better withstand water and heat stress and better utilize elevated CO2.

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Future development of new varieties that perform well in hot and dry conditions may also promote adaptation, but again the extent to which this will help remains unclear. Breeders and geneticists must continually weigh trade-offs between producing ample yield under stressful conditions and producing high yields under favorable conditions (Campos et al., 2004). At the higher warming levels considered in this report, it will be increasingly difficult to generate varieties with a physiology that can withstand extreme heat and drought while still being economically productive.

Although most studies have focused on crops, effects of climate change on livestock, aquaculture, and fisheries have also been considered in recent years. Livestock in parts of the world are raised mainly on grain and oilseed crops, in which case impacts will largely follow from the prices of these commodities and the costs of cooling or losing animals during heat waves.

In other cases livestock depend on grazing pasture and rangeland grasses, which follow a similar pattern to crops in that temperate regions will see modest gains up to ~2°C local warming, although forage quality may decrease with higher CO2 (Easterling et al., 2007). Although livestock systems are vulnerable in tropical areas, they may become increasingly relied upon as a strategy to cope with greater risks of crop failures (Thornton et al., recent study suggests that if global average warming were to be 2°C, catch potential could rise by 30-70% in high latitudes and fall by up to 40% in the tropics, as commercial species shift away from the tropics as the ocean warms (Cheung et al., 2010).

Food Prices and Food Security

One of the strengths of a global food system is that shortfalls in one area can be offset by surpluses in another. Models of the global food economy suggest that trade will represent an important but not complete buffer against climate change-induced yield effects (Easterling et al., 2007). Specifically, the comparative advantage will shift toward regions currently below optimum temperatures for cereal production (e.g., Canada) and away from hot tropical nations, with greater flows of food trade from north to south.

On average, studies suggest small price changes for cereals up to 2.5°C global temperature increase above pre-industrial levels, with significant increases for further warming, but there is considerable uncertainty around these estimates (see Box 5.2).

Implications of climate change for hunger, or the more technical term—food insecurity—follow in part from price changes, but also depend critically on how sources of income and other aspects of health are affected by climate. A useful rule of thumb provided by early studies suggested that malnourishment would rise by roughly 1% for each 2-2.5% rise in cereal prices (Rosenzweig, 1993). These and subsequent analyses often make untested assumptions about the ability of poor tropical nations to maintain economic growth in the face of declining agricultural productivity. For example, many African countries rely on agriculture for half or more of all economic activity, and losses in productivity could dampen purchasing power. Conversely, where price rises are greater than yield losses, households dependent on agricultural income could see net gains in food security.

In general, rural and urban workers with little or no landholdings are the most vulnerable to price shocks. A new generation of models that explicitly account for income sources among poor populations is emerging but yet to provide robust insights.

Also important could be climate-induced changes in the incidence of diarrheal and other diseases, which inhibit food security by reducing utilization of nutrients in food.

BOX 5.2 CLIMATE CHANGE IMPACTS ON GLOBAL CEREAL PRICES

Several modeling groups have analyzed future changes in global cereal markets in response to climate change. All operate by making estimates of yield responses in each region, and then inputting these into a model of global trade that computes the optimal mix of crop areas in different regions and the market-clearing price. Five models summarized by the recent IPCC report suggests small price changes for warming up to 2.5°C, and a nonlinear increase in prices thereafter (Easterling et al., 2007). Two important caveats relate to these estimates, however.

First, the yield changes used in these models usually assume considerable levels of farm level adaptations, which substantially reduce impacts. For example, in one prominent study cereal prices rose by 150% for a 5.2°C global mean temperature rise if farm-level adaptations were not included. When changes in planting dates, cultivar choices, irrigation practices, and fertilizer rates were simulated, these price changes were reduced to roughly 40% (Rosenzweig and Parry, 1994). Other studies often do not estimate impacts without adaptation, making it difficult to gauge assumptions. The costs of adaptation are also not considered in these studies, or reflected in price changes.

Second, most assessments have not adequately quantified sources of uncertainty. Although different climate scenarios are often tested, processes related to crop yield changes and economic adjustments are often implicitly assumed to be perfectly known. An additional source of uncertainty is potential competition with bio-energy crops for suitable land, which could limit the ability of croplands to expand in temperate regions as simulated by most trade models.