Food and Climate Change
The 2007 IPCC Assessment

Testimony of

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Introduction. My name is Bill Easterling. I am Professor of Geography and Agronomy at Penn State University and Director of the Penn State Institutes of Energy and the Environment. I have authored over 70 refereed scientific publications in the areas of food and climate, which are cited extensively, and I have given hundreds of presentations concerning my areas of expertise. My research interests focus especially on the simulation of agricultural adaptation to climate change. I have been a member of many national and international committees, including chairing the National Research Council's Panel on the Human Dimensions of Seasonal-to-Interannual Climate Variability. I have contributed to the efforts of the Intergovernmental Panel on Climate Change (IPCC) in several ways, and serve as a Convening Lead Author on Chapter 5 (Food, Fibre, Forestry, and Fisheries), and on the Technical Summary and the Summary for Policymakers of Working Group II of the Fourth Assessment Report.

The Food and Climate Challenge. The global expansion of the world's food supply in lock-step with growing world food demand is one of humanity's great achievements of the 20^{th} and first years of the 21^{st} centuries. Hunger surely persists in nearly every country today, but not because of shortage in the world's supply of food calories. By the latter third of this century, the world's farmers will be challenged to feed as many as 10-12 billion people who are likely to be, in the main, wealthier and more demanding in their food tastes than today. There are reasons to be optimistic that this challenge can be met in a future world that co-evolves with a stable climate, although emerging issues such as rising demand for bioenergy from crops could greatly increase pressures on food production. This overall challenge and any additional pressures will, in the long-run, be exacerbated by climate change.

As my colleague, Dr. Cynthia Rosenzweig notes in her testimony, the effects of recent climate variability and change on agriculture are being observed now in the form of longer growing seasons and faster temperature-regulated plant growth, especially in North America and Europe. As climate change intensifies in the future, so are those and many other agricultural effects expected to intensify. The newly released IPCC Working Group II report reaffirms a growing consensus among literally hundreds of field-based experiments and model-based simulation studies that rising atmospheric carbon dioxide concentration, hereafter [CO_2], and climate change will provide temporary benefits in some regions and for some crops and immediate loss in other regions and crops. In particular, our chapter documents regional trends that point to major crop yield loss in the low latitudes, where a majority of the poorest people in the world live, and temporary crop yield gains in the mid- to high latitudes.

I wish to speak to three major sets of findings concerning the potential consequences of future climate change for agricultural production at world and regional levels. They are: 1) the distribution of possible crop yield winners and losers across the Earth and the potential of adaptation to mediate that distribution; 2) the potential for rising [CO_2] to offset climate change-induced crop yield loss (or enhance yield gains); and 3) the effects of change in climate variability versus slow, steady climate change on crops. In addressing those points, I will rely on the recent IPCC Working Group II report exclusively.

Large regional variation in climate change effects on cereal crop productivity. Yield projections for the cereals maize (corn), wheat, and rice from nearly 70 studies that used physiologically-based plant simulation models are shown in Figure 1 below. The yield projections are expressed as percentage changes due to climate change with respect to current observed mean yields. Results are divided into “without adaptation” and “with adaptation” cases as discussed below. In the “without adaptation” case, model experiments were performed with the assumption that farmers take no action to respond to climate change. Without adaptation, the models broadly agree that, in mid- to high latitude regions (including North America), moderate to medium local increases in mean annual temperature (+1-3˚C), along with associated [CO_2] increase and precipitation changes, can have small beneficial impacts on crop yields (see Figure 1 below). Those increases are the result of longer growing seasons together with generally rising precipitation across many major grain belts.

Similar projections in low latitudes (tropics and parts of subtropics) indicate falling cereal yields with even moderate annual temperature increase (+1-2˚C) and associated [CO_2] increase. Cereal crops in low latitudes are currently grown at temperatures near the peak of their optimum photosynthetic range; any warming at all pushes crops past the edge of that range into suboptimal photosynthetic temperatures, hence yield loss.

Mean global temperature increases beyond approximately +3˚C result in a downturn of cereal yields in the mid- to high latitudes, with some exceptions (e.g., northern North America, northern Europe). This yield decrease occurs because of higher heat stress combined with increased evapotranspiration that begins to dry soils in spite of higher precipitation. Further warming has increasingly negative impacts on cereal yields globally. Decreasing yields globally eventually are expected to slow growth in agricultural production relative to growth in agricultural demand.

In the “with adaptation” case, model experiments in these same 70 studies were performed with the assumption that farmers take action by changing planting dates in order to accommodate earlier spring warm-up and cultivar selection for the longer growing seasons under climate change. The “with adaptation” results indicate that some of the yield loss reported above can be offset, again, depending on location. In the mid- to high latitudes, as shown in Figure 1, adaptation allows cereal yields to be maintained at or above current levels beyond ~+5˚C, but only up to ~+3˚C in the low latitudes, depending on the crop. Beyond ~+3˚C in the low latitudes, adaptation is no longer effective for cereals.

Potential for rising [CO_2] to offset climate change-induced crop yield loss (or enhance yield gains). Higher [CO_2] levels increase photosynthesis and water use efficiency in most plants, with certain crops (C_3 species such as wheat, rice, soybeans) showing greater response than other crops (C_4 species such as corn, sorghum). Recent experimental studies based on realistic field conditions indicate that, at 550 ppm CO_2 (CO_2 levels are currently at approximately 380 ppm) yields increase under unstressed conditions by 10-25% for C_3 crops, and by 0-10% for C_4 crops, consistent with previous IPCC estimates. Based on these recent studies, some researchers have argued that crop response to elevated CO_2 may be lower than previously thought, with consequences for crop model projections of yields and food supply. The basis for their argument is that the [CO_2] effects in current crop models are derived from earlier, less realistic experiments that tended to exhibit higher [CO_2] sensitivity of the crops than the recent studies. However, other researchers have carefully compared the results of the two experimental approaches and find that these new experimental findings are in fact consistent with previous. In addition, simulations of unstressed plant growth and yield response to elevated CO_2 in the main crop simulation models have been shown to be in line with recent experimental data, projecting crop yield increases of about 5-20% at 550 ppm CO_2. These findings reaffirm the validity of earlier projections of crop productivity and food production. It is worth pointing out, however, that current crop models do not have adequate internal structures for representing the effects of pests, disease, and certain extreme weather events (hail, hurricanes and other flooding), all of which lower the confidence in their projections.

A change in climate variability is worse for crops than slow, gradual climate change. Climate change is most likely to become evident to farmers not by gradual change in climate conditions, but rather by changes in the frequencies of damaging extremes such as droughts, excessive rainfall, and heat stress. Recent studies indicate that climate changes that include increased frequency of heat stress and droughts reduce crop yields and livestock productivity beyond the impacts due to changes in mean variables alone, creating the possibility for surprises. A number of simulation studies performed since the previous IPCC report have examined specific aspects of increased climate variability within climate change scenarios. For example, one study computed that, under scenarios of increased heavy precipitation, production losses due to excessive soil moisture would double in the U.S. by 2030. More frequent extreme events may lower long-term yields by directly damaging crops at specific developmental stages, such as temperature thresholds during flowering, or by making the timing of field applications more difficult, thus reducing the efficiency of farm inputs.

Synopsis. A large amount of progress has been made in understanding and projecting the effects of future climate change on agricultural production since the previous IPCC report, although significant uncertainties remain. It can now be stated with higher confidence than before that climate change is likely to challenge food security among the world's poorest people located in the low latitudes. It will be less troublesome to agricultural systems in the mid- to high latitude nations (like the USA), at least in the early stages of warming. Adaptation effectively maintains cereal yields in the mid- to high latitudes at or above current levels through moderate amounts of warming (~+4-5˚C), but it only protects low latitude cereal yields for a few degrees of warming (~+3˚C). The direct effects of rising atmospheric CO_2 levels on crop growth will offset some of the deleterious effects and enhance the beneficial effects of climate change. However, adaptation apart, low latitude cereal yields are projected to fall below current levels with modest warming, in spite of the beneficial effects of rising CO_2. In the mid- to high latitudes, CO_2 offsets yield loss for a while, but after ~+3˚C of global mean warming yields of the major cereal crops decline below current levels, again assuming no adaptation. If the climate changes are accompanied by increasing climate variability and frequencies of extreme events, crop yield losses are likely to occur at even smaller mean temperature increases than if variability is unchanged.

Figure 1. Temperate (mid-to high latitudes) vs. Tropics (low latitudes): Percent Change in Cereal Yield vs. Temperature Change (with/without adaptation) from 69 Modeling Studies