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US Agriculture and Climate Change: Perspectives from Recent Research

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Both weather and climate affect virtually every aspect of agriculture, from the production of crops and livestock to the transportation of agricultural products to market. Agricultural crop production is likely to be affected by both climate change and the associated increase in atmospheric CO_2. The projected changes in temperature and precipitation have the potential to affect crop yields either positively or negatively; elevated CO_2 levels increase plant photosynthesis and thus crop yields. Changes in climatic conditions are also likely to alter livestock performance and growth, grazing availability, irrigation water supply and demand, pest populations, and incidence of extreme events (floods, droughts, hail, etc.).

Economists in association with other disciplines have done many studies investigating the effects of projected climate change on US agriculture. Here I review results from the 1999–2000 US National Assessment conducted by a team of scientists (Reilly et al., 2002, USGCRP). In addition to considering the effects of climate change on markets, this assessment also examined the potential implications of climate change on environmental outcomes.

Note that the results in this section focus only on agricultural sector impacts. The National Assessment included analyses of the impacts of climate variability and change for regions in the United States and crosscutting sectoral analyses of agriculture, forestry, water, health, and coastal and marine resources. (For details, see National Assessment Synthesis Team, 2000.)

Climate Context

The US National Assessment of climate change is based on climate scenarios derived from world climate simulation models developed at the Canadian Centre for Climate Modelling and Analysis and the Hadley Centre in the United Kingdom. Although the physical principles driving these models are similar, they differ in representation of important processes and paint different views of the future. By using these two scenarios, a range of future climate conditions is captured. For example, the Canadian scenario projects a greater temperature increase (10°F, on average) over the next 100 years than does the Hadley scenario (7°F), whereas the Hadley model projects a much wetter climate than does the Canadian model. Both models project much wetter conditions, compared to present, over many agricultural areas in the United States.

Currently, climate scientists have less confidence in climate model projections about precipitation changes. For the next 100 years, the Canadian model projects the increase in precipitation to be largest in the Southwest and California, whereas the southern half of the nation east of the Rocky Mountains is projected to experience less precipitation. The percentage decreases are projected to be particularly large in eastern Colorado and western Kansas and across an arc running from Louisiana to Virginia. Projected decreases in precipitation are most evident in the Great Plains during the summer and in the East during both winter and summer. In the Hadley scenario, the largest increases in precipitation are also projected to be in the Southwest and Southern California, but the increases are smaller than those projected by the Canadian model. Overall, however, annual precipitation is projected to increase over the entire United States, with the exception of small areas along the Gulf Coast and in the Pacific Northwest.

Agriculture-Climate-Environment Interactions

Broader agriculture-climate-environment interactions are particularly important for understanding the impacts of climate change on agriculture. Several of these interactions were explored in the US National Assessment and are discussed below.

Land and Water Use. The overall increase in productivity meant that less crop, pasture, and grazing land was needed. The results of the economic modeling assessment also showed a 5–35% reduction in irrigated acres and in water demand for irrigation, due to the differential effects of climate change on productivity of irrigated versus non-irrigated crops and reductions in the use of most resources.

Pesticide Use. Empirical analysis of the relationship between pesticide use and climate was developed using historical observations across regions and time periods. The derived relationship was used to simulate future use of pesticides in the economic model. The modeling results suggest increased expenditures on pesticides for most major field crops in most states (corn, +10 to +20%; potatoes, +5 to +15%; cotton and soybeans, +2 to +5%; wheat, –15 to +15%). Although the increases were substantial, including this impact in the economic model only reduced the benefits of climate change by about $100 million, because pesticide expenditures are only 3–5% of the total cost of production on average.

Regional Climate-Environmental Quality Interactions. Within the National Assessment, more specific studies of the Edwards aquifer region (around San Antonio, Texas) and the Chesapeake Bay were conducted. In both regions, climate change could increase the threat to the environment, at least given the nature of the two climate scenarios used in the analysis. The climate models projected less precipitation in the Edwards aquifer region, thus increasing the demand for irrigation water from both urban and agricultural users. Resultant increased pumping of groundwater from the aquifer, combined with reduced rainfall, would threaten surface spring flows supported by the aquifer that are habitat of protected endangered species. Estimates were that the regional welfare loss was between $2.2–6.8 million per year due to climate change. This estimated loss did not include an estimate of the value of the nonmarket effects on endangered species habitat. If spring flows are to be maintained at the currently protected level, pumping must be reduced by 10–20% below the limit currently set, at an additional cost of $0.5–2 million per year.

Findings for the Chesapeake Bay region showed that nitrogen loadings to the Bay could increase by 25–50% under climate change. Corn acreage and fertilization levels were estimated to increase, thereby expanding nitrogen use. Increased precipitation led to greater runoff. Collectively, these results suggest that climate change may make attaining some environmental goals somewhat more difficult.

The most important implications of these precipitation changes are realized in estimates of soil moisture—a critical issue for agriculture. Soil moisture levels are determined by an intricate interplay among precipitation, evaporation, runoff, and soil drainage. By itself, an increase in precipitation would increase soil moisture. However, higher air temperatures also increase the rate of evaporation. The differences in the climate projections are accentuated in the soil moisture projections. For example, in the Canadian model, soil moisture decreases above 50% are common in the Central Plains, while in the Hadley model, this same region experiences soil moisture increases.

Climate Change Impacts on US Agriculture in 2030 and 2090

The US National Assessment used site-specific crop models to project yield alterations and an economic model to simulate trade and market effects. Crop modeling studies were conducted at 45 sites in the United States for wheat, maize, soybean, potato, citrus, tomato, sorghum, rice, and hay under dryland and irrigated conditions. Yields were simulated assuming current varieties and planting schedules, as well as assuming varieties and planting schedules changed to adapt to the changed climate conditions. Yield results and changes in water demand for irrigated crops from the crop models were used in an economic model to simulate national-level changes in production, resource use, and economic impact on farmers and consumers. Additional crops simulated in the economic model were barley, oats, sugar cane, sugar beet, and cotton. Yield reductions were quite large for some sites (particularly in the South and Plains States) and for the Canadian Climate model scenario that projected declines in precipitation and substantial warming in these regions.

In addition to the yield inputs, three additional adjustments in input levels were incorporated into the economic model used for the US National Assessment. Water supply forecasts from the national water assessment were used to change water available for irrigation. A positive relationship between input use (i.e., fertilizers) and yield and a generally negative relationship between livestock productivity and temperature were included based on previous work. Additional empirical analysis was conducted to find the relationship between climate and pesticide use for major crops. This work showed increased pesticide expenditures occurred with higher temperatures and greater precipitation (see box).

The net effects on sectoral economic welfare (income-equivalent measures of damages for consumers and producers) was found to be positive for the United States as a whole. Economic welfare benefits ranged from $0.8 to 7.8 billion in 2030 and from $3.2 to 12.3 billion in 2100 (2000 US$), as the production benefits in the heat-limited Northern US outweighed the losses in the South. These gains were distributed unevenly among domestic consumers, foreign consumers, and US producers. Producers generally suffered income losses, due to lower commodity prices, while consumers gained.

Substantial regional differences were found. Net production in some regions, for instance, was projected to decline in some scenarios, even though the production effect for the country as a whole was positive. Agricultural production in the Corn Belt and Lake States increased by 40–80% in the Canadian scenario but fell as much as 60% in the Southeast. In the Hadley scenario, all regions showed increased crop production, with a more than 100% increase in the Lake States. The Canadian scenario was much warmer and much drier, particularly in the 2030 period, thus projecting less positive effects on crop production overall and negative effects in the Southern and Plains areas of the United States.

Future Climate and Crop Variability

One of the implications of climate change may be an increase in weather variability. To address this issue, the US National Assessment examined two questions: (1) Is there evidence that changes in the mean climate conditions, as predicted by the two climate scenarios, could change the variability of crop yields? and (2) What would be the economic impact on the United States if El Nino-Southern Oscillation (ENSO) intensity and frequency increased, as projected by a recent climate model (Timmerman et al., 1999)? In statistical analysis of historical yield patterns and climate conditions, increased precipitation was found to reduce yield variability. Thus, when these statistical results were used to simulate the effects of climate change, yield variability declined for corn and cotton, because the climate scenarios generally showed greater precipitation for where these crops were grown. Results were somewhat mixed for other crops. Wheat yield variability tends to decrease under the Hadley Center climate and increase under the Canadian climate model, following the precipitation projections for the wheat-producing Great Plains regions. Soybean yield variability shows a uniform increase with the Hadley Climate Change Scenario.

Increased frequency of El Nino events was found to cause an average annual loss of economic welfare of $323 million. When both increased frequency and strength of ENSO were considered, the total welfare (consumers and producers) loss increased to $1,008 million, or about 5% of typical US agricultural net income. We also considered whether better forecasts of ENSO prior to the growing season could help farmers avoid these losses through changes in practices. Under current ENSO conditions, the value of improved forecasts was estimated at $453 million average annually. This rose to $544 million under changed frequency of ENSO and to $556 million with changes in frequency and intensity. The relationship between GHG-induced warming and ENSO are highly uncertain (and remain controversial), but these results do show extreme events to be a potential area of concern.

Concluding Comments

The results from the recent US National Assessment showed productivity benefits to northern areas with possible losses in warmer growing areas—particularly if precipitation does not increase. The overall results are similar to previous studies but are more positive in general. The range of crops studied was larger than before; this may have allowed more varied and positive effects, but the most likely explanation for these effects were that the newer climate scenarios showed larger increases in precipitation than previously forecast.

Precipitation predictions of climate models remain highly uncertain. Thus, confidence in these results awaits more study with a wider range of climate model scenarios. Even with these overall productivity gains, some areas of concern are suggested. If variability of climate were to increase, reduced productivity could result and lead to losses that could not be offset even with better interannual forecasts. In addition, regional environmental goals, often affected by a complex interaction of land use, climate, cropping practice, and competing demands for resources, could become more difficult to achieve.

For More Information

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