Uncertainty, Thresholds and Surprises

Some observers believe that climate change will exert its influence so slowly--a fraction of a degree per decade--that the effects will be barely noticeable in the midst of other technological and economic changes. Others emphasize the need to study the potential for what are called "threshold effects"--i.e., the abrupt and disproportionate shifts in production that may be triggered when critical levels of certain factors are surpassed. Unexpected consequences or "surprises" may well accompany the buildup of greenhouse gases. Even if climate changes gradually, it will slowly affect the range of options available for agriculture in any given region. Under changing climate conditions, farmers' past experience will be a less reliable predictor of what is to come. These and other uncertainties must be taken into account explicitly in climate change impact studies.

Uncertainty

The uncertainty inherent in predictions is a very important feature of climate change impact studies, and work has begun to develop explicit methods to deal with the concept. Earlier studies had often used "best estimate" scenarios that were based on the mid-points of the predicted range of expected change in temperature, precipitation, or other parameters. Including the entire range from the upper to the lower bounds of predicted effects is a more prudent and realistic approach, which may clarify the way that uncertainty can propagate throughout a modeled or a real system.

Other uncertainties derive from the fast pace and unpredictable directions of future social, economic, political, and technical changes. The world of the coming century will be different in many ways; unforeseeable developments in other sectors may change the way in which agriculture responds to climate change. Questions regarding population (i.e., for how many people need the world's agricultural system provide?) and technological change (can productivity continue to improve?) are particularly relevant and should be explored with upper and lower bounds of possible projections.

Thresholds

Some effects, such as the flooding of a river or the withering of a crop, come into play only after certain limiting conditions or thresholds have been crossed. The identification of thresholds in climate change impact research involves analyzing the effects of different levels of climate forcing on an agroecosystem to identify the critical conditions under which the response of crops will abruptly change. These critical levels can involve either natural or socioeconomic factors, and both should be considered. For example, in the biophysical domain threshold temperatures have been defined for many specific crop processes, notwithstanding the complexity of interactions among temperature, amount and duration of sunlight, nutrients, and water supply. Crop models have been developed accordingly to test the combined effects of environmental variables on crop growth and yield.

In the socioeconomic domain, defining critical levels of warming is even more challenging, due to the intricate interplay of supply, demand, and prices, and to the characteristic adaptability of agriculture as a managed human system. Here, determining critical levels of warming involves defining relative impacts on producers and consumers in diverse geographic and social groups.

The critical levels of climatic change that affect crop yields can be identified through computer-based sensitivity tests and crop models. Results of a crop modeling study that estimated the effects of a 2°C and 4°C temperature rise on yields of wheat, rice, corn, and soybeans are shown in Fig. 3. They were derived by first modeling the simulated effect on crop yields for a wide range of latitudes and then applying what was found to current production, nation by nation, to derive a result for the world as a whole. When only temperature effects were considered, aggregate crop yields showed an ever increasing drop in response to higher temperatures, with loss in yields approximately doubling from the +2 to +4°C cases. When the direct physiological effects of CO_2 on crop growth and water use were included, the picture changed, but only for the lower temperature increase: a 2°C temperature rise increased aggregated crop yields on a global basis, while a 4°C rise led to an overall decrease, as is shown in the **figure**. The salutary effect of a 2° increase did not apply throughout the world: in some modeled locations in semi-arid and subtropical regions, even a 2° rise resulted in diminished yield. These results suggest the existence of a possible temperature threshold affecting global grain yields, given current crop varieties and crop management techniques.

Surprise

An even more challenging task is to estimate the probability of coincidental events that might happen in conjunction with global warming, spanning the range between low probability catastrophic events (called "surprises") and higher probability gradual changes in climate and associated environmental effects. A seemingly small change in one variable--for example, rainfall--may trigger a major unsuspected change in another; for example, droughts or floods might possibly disrupt the transport of grain on rivers. Moreover, one "surprise" may then lead to another in a cascade, since biophysical and social systems are interconnected. Computer-aided studies based on what are called *complex systems* and *chaos* theory may provide conceptual and analytical tools for anticipating and preparing for surprises, in agriculture as in other systems.

Identifying potential surprises and communicating them to the public and to policy makers may help build the resilience that is needed to anticipate and mitigate harmful effects in timely fashion. Surprises related to global climate change may be both environmental and societal. Among the first of these are changes in patterns of atmospheric circulation and precipitation on the seasonal- to-interannual time scale, such as might result from varying patterns of El Niñ o events in the eastern equatorial Pacific. Such inter- seasonal variations (rather than the very gradual change in long-term averages) are likely to be the climatic effects that farmers actually feel in their year-to-year operations. Among the second are increases in the migration of people across national borders in consequence of famine.

Such events can be better accommodated if their causes and potential effects are anticipated in advance. Their study can be aided by efforts to integrate across conventional scientific disciplines, to support a variety of research approaches, and to consider results that lie outside the range of conventional wisdom and experience. Beyond the theoretical study of environmental surprise, it seems also worthwhile to increase the flexibility of social structures with a view to reducing vulnerability to abrupt perturbations. Such societal preparedness might include an intentional diversification of productive and technological systems (such as provision for reserve rangeland and supplementary irrigation for the eventuality of drought), the establishment of disaster coping and entitlement systems, and the creation of management systems that are capable of adapting to and learning from surprises. Adjustments in livestock populations represent one of the first lines of defense against the surprises that can result from short-term fluctuations in crop production.