CLIMATE CHANGE AND AGRICULTURE

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Summary

Climate is the primary determinant of agricultural productivity. Reductions in agricultural productivity will affect the supply of agricultural commodities and increase prices paid by consumers. Increases in food prices translate into reductions in human well-being. Because of these linkages, concern has been expressed over the potential effects of climate change on agriculture. This article reviews the biological and economic dimensions of the effects of climate change on agriculture, drawing on a decade of studies addressing the topic. Biological evidence suggests that changes in climate variables such as temperature and precipitation, and associated water supplies, will change the yields of many economically important crops and the geographical distribution of their production. The economic implications of these changes vary by crop and country. Shifts in the geographical distribution of crops globally is expected to have effects on environmental attributes, including more air and water pollution and losses of critical wildlife habitats. Agriculture may also play a role in mitigating climate change through the sequestration of carbon in soils and in changes in farming practices to reduce the production of certain greenhouse gases. These potential mitigation strategies and opportunities are reviewed in this article.

1. Introduction

Climate is the primary determinant of agricultural productivity. Food and fiber production, in turn, is essential for sustaining and enhancing human welfare. Hence, agriculture has been a major focus in recent discussions about the effects of climate change. In fact, the United Nations Framework Convention on Climate Change (FCCC) views the sustainability of food production as paramount in the objectives for stabilizing greenhouse-gas (GHG) emissions, stating that emissions should be stabilized at a level that "ensures that food production is not threatened."

This article summarizes the state of knowledge covering climate change and agriculture, building on several recent summaries. Findings from the U.S. are highlighted, although general evidence regarding world agricultural production are reviewed. Estimates of changes in agricultural production are dependent upon how climate changes at regional scales; assumptions regarding adaptation by producers and consumers; future technologies; population and income growth; land degradation; macroeconomic conditions; changes in international trade barriers; and changes in social and political conditions. The results are also sensitive to the assessment methods and models employed in these estimation exercises.

Section 2 highlights the linkages between agriculture and climate. In Section 3, the biophysical dimensions of climate change in terms of crop and livestock performance are described. Section 4 addresses the issues of adaptation and adjustment costs in the agricultural system. Section 5 summarizes the effects of climate change on crop and livestock yields in terms of those effects on production, prices, and economic welfare. Section 6 presents information concerning the possible consequences of climate change for environmental quality and Section 7 discusses the possible role of agriculture in mitigating GHG emissions.

2. Agriculture and Climate

Agronomic and economic impacts from climate change depend primarily on two factors: (1) the rate and magnitude of change in climatic variables and the biophysical effects of these changes and (2) the ability of agricultural systems to adapt to changing environmental conditions. Each of these aspects is reviewed below.

2.1. The Biophysical Dimensions

The agroecosystem is a complex system of interactions between atmosphere and climate, nutrients and soils, and biological factors such as plant type and pressures from biological stressors (i.e. weed competition, insects, and diseases). Both crop and livestock systems are influenced by many climatic and environmental factors, many of which work in concert either synergistically or antagonistically. Crops, for example, respond directly to changes in temperature, moisture, and carbon dioxide (CO_2). Livestock production may be affected by heat-induced appetite suppression, changes in the supply of feed crops, and changes in the extent and productivity of pasture and grassland. Factors such as temperature, rainfall, and CO_2 levels are discussed below.

2.1.1. Temperature

Temperature affects the rate of photosynthesis, and hence the rate at which plants absorb (and respire) CO_2 from (and to) the atmosphere. Temperature increases lead to higher respiration rates, can reduce crop yields, and, for example, could lead to lower quality grain because the higher temperatures result in a shorter grain filling period and, hence, smaller and lighter grains. Optimum temperature ranges vary for different crops and crop varieties. For example, the optimal range for many C_3 plants, such as wheat, rice, and soybeans, is 15°C–20°C, and for C_4 plants, such as corn, sorghum, and sugar cane, it is 25°C–30°C. Climatic changes can alter the suitable geographic range of crops, leading to possible changes in the types and extent of crops in some areas. Temperatures in many low-latitude countries are often close to the thermal tolerances of many crops grown in these countries.

Temperature changes can interact very closely with changes in the availability of water and nutrients. For example, elevated temperatures lead to increased evaporation and transpiration rates and, hence, diminished soil moisture (depending, of course, on changes in rainfall patterns and other climatic variables). Soil nutrient levels could be affected by increased rates of decomposition induced by higher temperature. Nutrient cycling is an important area of investigation.

2.1.2. Rainfall

Without increases in rainfall, soil moisture will decrease as a result of higher temperatures. Averaged across the globe, rainfall is expected to increase. The changes, however, will not be uniform; some areas may experience decreases while others may receive increases. In addition, some evidence suggests that more rain will fall in heavy rainfall events, and dry periods between such events may increase in some areas. The combined effect of rainfall and temperature changes on soil moisture will vary by location and by season. In areas where dryland crop yields are currently limited by soil moisture, increases in soil moisture during critical development stages would decrease water stress and increase yields (ignoring the direct effect of temperature on plant physiology); decreases in soil moisture in these areas would decrease yields.

2.1.3. Carbon Dioxide Concentrations

Increasing atmospheric CO_2 concentrations generally increase the rate of photosynthesis, and can also increase water-use efficiency by plants. This is sometimes referred to as the "CO_2 fertilization effect," and it can partially mitigate the adverse effects of higher temperatures. However, the extent of this effect is uncertain and depends on which factors are most limiting to plant growth and development. Some studies have estimated yield increases of 30% and 7% for many C_3 and C_4 crops, respectively. However, there is concern about possible feedback effects that might further contribute to higher temperatures. The increase in water-use efficiency occurs because CO_2 fertilization allows plants to reduce the rate of gas exchange in leaves (i.e. plants reduce the diameter of their stomates). Less water, therefore, is transpired across leaves, resulting in higher leaf temperatures that in turn may contribute to climate change by reducing precipitation and warming the surrounding atmosphere. Hence, water-use efficiency attributed to CO_2 concentrations may be offset somewhat by reductions in soil moisture.

Estimates of fertilization effects are primarily based on greenhouse experiments in which water and nutrients are not limiting factors on plant growth. The experiments also do not address competition from weeds, which will also benefit from CO_2, or changes in feeding of insects on crops, which may increase in a CO_2-enriched world. Under field conditions, such factors may reduce the benefits of CO_2 from those that have been achieved in experimental settings.

2.1.4. Climate Variability and Extreme Events

Crop and livestock systems are influenced by variation in climate and extreme events. There is significant value in understanding the sensitivity of agriculture to (and possibly projecting) changes in variability. For example, recent advances linking long-run weather forecasts to the El Niño/Southern Oscillation phenomena (ENSO) events have the potential to benefit agriculture by providing valuable information about precipitation and temperature. Climate variability affects agricultural crops mainly through the frequency of climate extremes, which in many cases are more strongly affected by changes in variability compared to changes in average climate. Climate variability is likely to change as radiative forcing increases average temperatures. Small changes in climate variability, as well as climate means, can produce relatively large changes in the frequency of extreme events. Some evidence indicates that the hydrologic cycle will be intensified such that droughts and floods will become more severe in some places, for example, the United States and other low- to mid-latitude regions, which will most likely experience increased rates of evapotranspiration as a result of climate change. Where droughts and floods become more severe or frequent, agricultural losses would increase. Effects of changes in climate variability or extreme events are not well understood and are not included in the studies summarized in this article.

2.1.5. Indirect Effects

In addition to the direct effects of climate change on agriculture, there are important indirect effects that can negatively affect production; with few exceptions, these have been largely ignored in the assessment of climate change impacts. For example, sea-level rise can inundate agricultural areas, or at least require mitigation efforts along lowlying coastal regions. Indirect effects may also arise from changes in the incidence and distribution of pests and pathogens, rates of soil erosion and degradation, ozone levels, UV-B radiation, changes in runoff and groundwater recharge rates, and changes in capital or technological requirements such as surface water storage and irrigation methods.

2.2. The Dimensions of Human Response

The consequences of the biophysical impacts of climate change will be influenced by the human responses to these impacts. Societies have adapted agriculture to a wide variety of climates around the world. Within each climate region, people have developed strategies to cope with considerable climate variability, to increase the reliability of food supplies, and to reduce economic risks. Over time, agricultural systems have adapted to changing economic conditions, changing resource supplies, and growing food demands by adopting new technologies and practices, changing cultivated acreage, and changing institutional arrangements.

The flexibility of agricultural systems suggests there is a significant human potential to adapt to climate change. Farm level adaptations can be made in planting and harvest dates, crop rotations, selection of crops and crop varieties for cultivation, water consumption for irrigation, use of fertilizers, and tillage practices. Appropriate choices can lessen the yield losses that might result from climate change, or improve yields where climate change is beneficial. At the market level, yield changes will generate price and supply changes that can signal further opportunities to adapt. For example, cultivated acreage of a crop may expand in regions that gain a comparative advantage from climate change and contract in areas that lose a comparative advantage. Trade, both international and intranational, can reallocate supplies of agricultural commodities from areas of relative surplus to areas of relative scarcity. In the longer term, anticipatory adaptation might include the development and use of new crop varieties that offer advantages for the anticipated future climate, or investments in new water-management and irrigation infrastructure as insurance against potentially less reliable rainfall.

The biophysical impacts and human responses together will determine how yields and livestock productivity will be affected by climate change. In turn, yields and productivity changes will determine the social and economic consequences of climate change (the social and economic consequences will also be modified in important ways by human responses). For example, if grain yields are negatively affected in a region, farmers may switch to other crops that are less negatively affected, or that will produce greater yields as a consequence of climate change. Through trade with other regions, consumers in the region with reduced grain production may continue to be supplied with grain and grain products.

Research on potential human responses shows that they are the important determinants of the consequences of climate change. However, predicting the responses that would be made and their effectiveness is a challenging task. There are a variety of obstacles that may prevent appropriate responses, such as imperfect information about future climate and its biophysical effects, scarcity of capital, institutional barriers, and other factors. It should also be noted that, even if appropriate responses are made, some areas may nonetheless suffer severe consequences that cannot be avoided through adaptation to climate change.

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Biographical Sketch

Richard Adams is professor of agricultural and resource economics at Oregon State University. Dr. Adams received a B.S. in resource management in 1968; an M.S. in agricultural economics in 1971, and a Ph.D. in 1975 from the University of California, Davis. Dr. Adams was selected a Distinguished Fellow by the American Agricultural Economics Association in 2001. He was also recently named one of the top four percent of academic economists in the world. in *Who's Who in Economics*. He served as editor of the *American Journal of Agricultural Economics* and associate editor for *Water Resources Research* and *the Journal of Environmental Economics and Management*. Dr. Adams has published over 140 peer-reviewed books, book chapters, and journal articles. He is a member of various government committees dealing with climate change, water resources management, and other environmental issues. Dr. Adams' current research interests focus on the economic effects of water pollution, the implications of climate change for agriculture and water resources, and the tradeoffs between agricultural activity and environmental quality.