Anticipated Responses of Agroecosystems

Effects of enhanced CO_2 on crop growth

Plants grow through the well-known process of *photosynthesis*, utilizing the energy of sunlight to convert water from the soil and carbon dioxide from the air into sugar, starches, and cellulose--the *carbohydrates* that are the foundations of the entire **food chain**. CO_2 enters a plant through its leaves. Greater atmospheric concentrations tend to increase the difference in partial pressure between the air outside and inside the plant leaves, and as a result more CO_2 is absorbed and converted to carbohydrates. Crop species vary in their response to CO_2. Wheat, rice, and soybeans belong to a physiological class (called *C3 plants*) that respond readily to increased CO_2 levels. Corn, sorghum, sugarcane, and millet are *C4 plants* that follow a different pathway. The latter, though more efficient photosynthetically than C3 crops at present levels of CO_2, tend to be less responsive to enriched concentrations. Thus far, these effects have been demonstrated mainly in controlled environments such as growth chambers, **greenhouses**, and plastic enclosures. Experimental studies of the long-term effects of CO_2 in more realistic field settings have not yet been done on a comprehensive scale.

Higher levels of atmospheric CO_2 also induce plants to close the small leaf openings known as *stomates* through which CO_2 is absorbed and water vapor is released. Thus, under CO_2 enrichment crops may use less water even while they produce more carbohydrates. This dual effect will likely improve water-use efficiency, which is the ratio between crop biomass and the amount of water consumed. At the same time, associated climatic effects, such as higher temperatures, changes in rainfall and soil moisture, and increased frequencies of extreme meteorological events, could either enhance or negate potentially beneficial effects of enhanced atmospheric CO_2 on crop physiology.

Effects of higher temperature

In middle and higher latitudes, global warming will extend the length of the potential growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season. Crop-producing areas may expand poleward in countries such as Canada and Russia, although yields in higher latitudes will likely be lower due to the less fertile soils that lie there. Many crops have become adapted to the growing-season daylengths of the middle and lower latitudes and may not respond well to the much longer days of the high latitude summers. In warmer, lower latitude regions, increased temperatures may accelerate the rate at which plants release CO_2 in the process of *respiration*, resulting in less than optimal conditions for net growth. When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. If nighttime temperature minima rise more than do daytime maxima--as is expected from greenhouse warming projections--heat stress during the day may be less severe than otherwise, but increased nighttime respiration may also reduce potential yields. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced yield.

Available water

Agriculture of any kind is strongly influenced by the availability of water. Climate change will modify rainfall, evaporation, runoff, and soil moisture storage. Changes in total seasonal precipitation or in its pattern of variability are both important. The occurrence of moisture stress during flowering, pollination, and grain-filling is harmful to most crops and particularly so to corn, soybeans, and wheat. Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress; as a result there will be a need to develop crop varieties with greater drought tolerance.

The demand for water for irrigation is projected to rise in a warmer climate, bringing increased competition between agriculture--already the largest consumer of water resources in semiarid regions--and urban as well as industrial users. Falling water tables and the resulting increase in the energy needed to pump water will make the practice of irrigation more expensive, particularly when with drier conditions more water will be required per acre. Some land--such as the region of the U.S. supplied by the Ogallala aquifer (including parts of Nebraska, Oklahoma, Texas, Colorado, and New Mexico)--may be taken out of irrigation, following a trend that has already begun, with loss of considerable prior investment. Peak irrigation demands are also predicted to rise due to more severe heat waves. Additional investment for dams, reservoirs, canals, wells, pumps, and piping may be needed to develop irrigation networks in new locations. Finally, intensified evaporation will increase the hazard of salt accumulation in the soil.

Climate variability

Extreme meteorological events, such as spells of high temperature, heavy storms, or droughts, disrupt crop production. Recent studies have considered possible changes in the variability as well as in the mean values of climatic variables. Where certain varieties of crops are grown near their limits of maximum temperature tolerance, such as rice in Southern Asia, heat spells can be particularly detrimental. Similarly, frequent droughts not only reduce water supplies but also increase the amount of water needed for plant transpiration.

Soil fertility and erosion

Higher air temperatures will also be felt in the soil, where warmer conditions are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect fertility. Additional application of fertilizer may be needed to counteract these processes and to take advantage of the potential for enhanced crop growth that can result from increased atmospheric CO_2. This can come at the cost of environmental risk, for additional use of chemicals may impact water and air quality. The continual cycling of plant *nutrients*--carbon, nitrogen, phosphorus, potassium, and sulfur--in the soil-plant-atmosphere system is also likely to accelerate in warmer conditions, enhancing CO_2 and N_2O greenhouse gas emissions.

Nitrogen is made available to plants in a biologically usable form through the action of bacteria in the soil. This process of *nitrogen fixation*, associated with greater root development, is also predicted to increase in warmer conditions and with higher CO_2, if soil moisture is not limiting. Where they occur, drier soil conditions will suppress both root growth and decomposition of organic matter, and will increase vulnerability to wind erosion, especially if winds intensify. An expected increase in convective rainfall--caused by stronger gradients of temperature and pressure and more atmospheric moisture--may result in heavier rainfall when and where it does occur. Such "extreme precipitation events" can cause increased soil erosion.

Pests and diseases

Conditions are more favorable for the proliferation of insect pests in warmer climates. Longer growing seasons will enable insects such as grasshoppers to complete a greater number of reproductive cycles during the spring, **summer**, and autumn. Warmer winter temperatures may also allow larvae to winter-over in areas where they are now limited by cold, thus causing greater infestation during the following crop season. Altered wind patterns may change the spread of both wind-borne pests and of the bacteria and fungi that are the agents of crop disease. Crop-pest interactions may shift as the timing of development stages in both hosts and pests is altered. Livestock diseases may be similarly affected. The possible increases in pest infestations may bring about greater use of chemical pesticides to control them, a situation that will require the further development and application of integrated pest management techniques.

Sea-level rise

Global warming is predicted to lead to thermal expansion of sea water, along with partial melting of land-based glaciers and sea-ice, resulting in a rise of sea level which may range from 0.1 to 0.5 meters (4 to 20 inches) by the middle of the next century, according to present estimates of the Intergovernmental Panel on Climate Change (IPCC). Such a rise could pose a threat to agriculture in low- lying coastal areas, where impeded drainage of surface water and of groundwater, as well as intrusion of sea water into estuaries and aquifers, might take place. In parts of Egypt, Bangladesh, Indonesia, China, the Netherlands, Florida, and other low-lying coastal areas already suffering from poor drainage, agriculture is likely to become increasingly difficult to sustain. Some island states are particularly at risk.