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RESEARCH ARTICLE

CLIMATE CHANGE AND ITS IMPACT ON AGRICULTURE

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ABSTRACT

Climate change will affect on vegetation directly because of increased CO_2 concentration and green house gases and indirectly through stratospheric ozone layer depletion. Increased CO_2 level could increase photosynthesis and water use efficiency. However high temperature and green house gases will modify rainfall, evaporation, runoff and soil moisture storage and will adversely affect growth and productivity. The increased amount of ultraviolet (UV) radiation due to depletion of stratospheric ozone layer will exert its deleterious effect on growth and productivity by destruction of chlorophyll and reducing photosynthetic rate.

INTRODUCTION

Climate change and agriculture are interrelated processes, both of which take place on a global scale. Global warming is believed to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial run-off, precipitation and the interaction of these elements. These conditions determine the carrying capacity of the biosphere to produce enough food for the human beings as well as other domesticated animals. The overall effect of climate change on agriculture will depend on the balance of these effects. Assessment of the effects of climate changes on agriculture might help to properly anticipate and adapt farming to maximize agricultural production. At the same time, agriculture has been shown to produce significant effects on climate change, primarily through the production and release of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, and also by altering the Earth's land cover, which can change its ability to absorb or reflect heat and light.

Climate change is defined as change in climate over time, either due to natural variability or as a result of human activity. Global climate change is caused by the accumulation of greenhouse gases in the lower atmosphere. The global concentration of these gases is increasing, mainly due to human activities, such as the combustion of fossil fuels and deforestation. The atmospheric concentration of carbon dioxide, the main greenhouse gas, has increased by 30 percent since preindustrial times. Projections of future climate change are derived from global climate model or general circulation model (GCM) experiments. Climatologists of the Intergovernmental Panel on Climate Change (IPCC) review the results of these experiments for global and regional assessments. It is estimated that global mean surface temperature will rise by 1.5° to 3.5° C by 2100. This rate of warming is significant. Large changes in precipitation, both increases and decreases, are forecast, largely in the tropics. Climate change is very likely to affect the frequency and intensity of weather events, such as storms and floods, around the world. Sea level will also rise as a result of climate change due to the thermal expansion of the oceans and the melting of the mountain glaciers. Global mean sea level is anticipated to rise by 15 to 95 centimeters by 2100. Sea level rise will increase vulnerability to coastal flooding and storm surges. The faster the climate changes, the greater will be the risk of damage to the environment.

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Impact on agriculture

Most agricultural impacts studies are based on the results of general circulation models (GCMs). These climate models indicate that rising levels of greenhouse gases are likely to increase the global average surface temperature by 1.5-4.5 C over the next 100 years, raise sea-levels (thus inundating farmland and making coastal groundwater saltier), amplify extreme weather events such as storms and hot spells, shift climate zones pole ward, and reduce soil moisture. Impacts studies consider how these general trends would affect agricultural production in specific regions. Climate is a primary and the most important determinant of agricultural productivity. The more the climate is conducive for crop growth, greater the returns in terms of crop yield. In turn, food and fiber production is essential for sustaining and enhancing human welfare. Hence, agriculture has been a major concern in the discussions on climate change. As a thumb rule, climate variability and change may have an overall negligible effect on total food production (Rosenwieg and Parry, 1994); however, the regional impacts are likely to be substantial and variable, with some regions benefiting from an altered climate and other regions adversely affected. Generally, food production is likely to decline in most critical regions whereas in some developed countries, it may actually benefit agriculture where technology is more available and if appropriate adaptive adjustments are employed.

Climate change is expected to influence crop and livestock production, hydrologic balances, input supplies and other components of agricultural systems. However, the nature of these biophysical effects and the human responses to them are complex and uncertain. For example, crop and livestock yields are directly affected by changes in climatic factors such as temperature and precipitation and the frequency and severity of extreme events like droughts, floods, and wind storms. In addition, carbon dioxide is fundamental for plant production; rising concentrations have the potential to enhance the productivity of agro-ecosystems. Climate change may also change the types, frequencies, and intensities of various crop and livestock pests; the availability and timing of irrigation water supplies; and the severity of soil erosion. 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. $_{CO2}$ 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 $_{CO2}$ is absorbed and converted to carbohydrates. Crop species vary in their response to $_{CO2}$. Wheat, rice, and soybeans belong to a physiological class (called C_3 plants) that respond readily to increased CO2 levels. Corn, sorghum, sugarcane, and millet are C_4 plants that follow a different pathway. The latter, though more efficient photosynthetically than C_3 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.

a) Crop growth

Crop growth is influenced by many environmental factors and these factors, such as moisture and temperature, may act either synergistically or antagonistically with other factors in determining yields (Waggoner 1983). Controlled field experiments can generate information on how the yield of a specific crop variety responds to a given stimulus, such as water or fertilizer. However, by their nature, such controlled experiments consider only a limited range of environmental factors. Higher levels of atmospheric $_{CO2}$ induce plants to close the small leaf openings known as stomates through which CO_2 is absorbed and water vapour is released. Thus, under higher CO_2 environment 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. But 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 $_{CO2}$ on crop physiology.

In India the direct impact of climate change would affect plant growth, development and yield due to changes in rainfall and temperature. Increase in temperature would reduce crop duration, increase crop respiration rates, change the pattern of pest attack and new equilibrium between crops and pests hasten mineralization in soils and decrease fertilizer use efficiency. All these could considerably affect crop yields in long run. In general the simulation results indicate that increasing temperature and decreasing solar radiation levels pose a serious threat in decreasing growth and yield of agricultural crops. Increased $_{CO2}$ levels are expected to favour growth and increase crop yields and therefore, will be helpful in counteracting the adverse effects of temperature rise in future. On global level climate change effects will change the crop production areas. 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 pole ward in countries although yields in higher latitudes will likely be lower due to climate change. Many crops have become adapted to the growing season, day lengths 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 $_{CO2}$ in the process of respiration, resulting in less than optimal conditions for net growth. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced yield.

b) Available water

Agriculture of any kind in any part of the world is strongly influenced by the availability of water. Climate change will modify rainfall, evaporation, runoff, and soil moisture storage. Changes in either total annual precipitation or in its pattern of occurrence are both important from agricultural point of view. The occurrence of moisture stress during flowering, pollination, and grain-filling is harmful to most of the crops. 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 water requirement for irrigation is expected to increase 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. Peak irrigation demands are also predicted to rise due to more severe heat waves.

c) Pest and disease

Generally it has been observed that warmer climate is more conducive for the proliferation of insect pests. Extended and longer growing seasons will enable insect pests 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.

c) Effects of higher temperature

There is now clear evidence for an observed increase in global average temperatures and change in rainfall rates during the 20th century (Easterling, 1999; IPCC, 2001; Jung *et al*., 2002; Balling Jr and Cerveny, 2003; Fauchereau *et al*., 2003) around the world. The most prominent climatic changes in recent times is the increase in the atmospheric temperatures due to increased levels of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O) and chlorofluoro carbons (CFCs). Because of the increasing concentrations of those greenhouse gases, there is much concern about future changes in our climate and direct or indirect effect on agriculture (Garg *et al*., 2001; IPCC, 2001; Krupa; 2003; Aggarwal, 2003; Bhatia *et al*., 2004). As a result of rise in temperatures, the length of potential growing season will extend in middle and higher latitudes, 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 towards poles, 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 day lengths 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.

d) Erosion and fertility

The warmer atmospheric temperatures observed over the past decades are expected to lead to a more vigorous hydrological cycle, including more extreme rainfall events. Erosion and soil degradation is more likely to occur. Soil fertility would also be affected by global warming. However, because the ratio of carbon to nitrogen is a constant, a doubling of carbon is likely to imply a higher storage of nitrogen in soils as nitrates, thus providing higher fertilizing elements for plants, providing better yields. The average needs for nitrogen could decrease, and give the opportunity of changing often costly fertilisation strategies. Due to the extremes of climate that would result, the increase in precipitations would probably result in greater risks of erosion, but at the same time providing soil with better hydration, according to the intensity of the rain. The possible evolution of the organic matter in the soil is a highly contested issue: while the increase in the temperature would induce a greater rate in the production of minerals, lessening the soil organic matter content, the atmospheric CO_2 concentration would tend to increase it.

e) Sustainability and food security

Agricultural sustainability can be fluctuated by climate change in two interrelated ways, firstly by diminishing the long-term ability of agro-ecosystems to provide food and fiber for the world's population and secondly, by inducing shifts in agricultural regions that may encroach upon natural habitats, at the expense of floral and faunal diversity. Global warming may encourage the expansion of agricultural activities into regions now occupied by natural ecosystems such as forests, particularly at mid- and high-latitudes. Forced encroachments of this sort may thwart the processes of natural selection of climatically-adapted native crops and other species. In addition to the direct effects of climate change on agriculture, there are important indirect effects that can affect production. For example, sea level rise can inundate or require mitigation efforts along low-lying coastal regions. Indirect effects may also arise from alterations in the growth rates and distribution of weeds, pests and pathogens, rates of soil erosion and degradation, and alterations in ozone levels or UV radiations. While the overall global impact of climate change on agricultural production may be small, regional vulnerabilities to food deficits may increase, due to problems of distribution and marketing food to specific regions and groups of people. For subsistence farmers and more so for people who now face a shortage of food, lower yields may result not only in measurable economic losses, but also in malnutrition and even famine. In general, the tropical regions appear to be more vulnerable to climate change than the temperate regions for several reasons. On the biophysical side, temperate C_3 crops are likely to be more responsive to increasing levels of CO_2. Second, tropical crops are closer to their high temperature optima and experience high temperature stress, despite lower projected amounts of warming. Third, insects and diseases, already much more prevalent in warmer and more humid regions, may become even more widespread.

Conclusion

Climate change is believed to affect agriculture in near future and there is need for near-term efforts to mitigate climate change. In view of the projected long term outcomes of climate change, the global agricultural production system appears able to continue high productivity without global threat to food security although substantial regional disturbances can occur. In terms of climate change mitigation, there is vulnerability in terms of agricultural production with mitigation efforts competing with traditional agricultural food production. Climate change mitigation effects may largely benefit producers at the expense of consumers and help support agricultural producer incomes.

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