# Impact of Climate Change on Agriculture

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*Abstract*— **Climate change and agriculture are inter-related processes, both of which take place on a global scale. Global warming is projected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial run-off, precipitation and interaction of these elements. The overall effect of climate change on agriculture will depend on the balance of these effects. Assessment of the effects of global climate changes on agriculture might help to properly anticipate and adapt farming to maximize agricultural production. This paper discusses probable impacts of climate change on agriculture.**

***Index Terms***— Agriculture, Crop, Climate Change, Drought, IPCC.

## I. INTRODUCTION

Agriculture represents a core part of the Indian economy and provides food and livelihood activities to much of the Indian population. While the magnitude of impact varies greatly by region, climate change is expected to impact on agricultural productivity and shifting crop patterns. The policy implications are wide-reaching, as changes in agriculture could affect food security, trade policy, livelihood activities and water conservation issues, impacting large portions of the population.

The agricultural sector represents 35% of India's Gross National Product (GNP) and as such plays a crucial role in the country's development. Food grain production quadrupled during the post-independence era; this growth is projected to continue. The impact of climate change on agriculture could result in problems with food security and may threaten the livelihood activities upon which much of the population depends. Climate change can affect crop yields (both positively and negatively), as well as the types of crops that can be grown in certain areas, by impacting agricultural inputs such as water for irrigation, amounts of solar radiation that affect plant growth, as well as the prevalence of pests.

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Despite technological advances, such as improved varieties, genetically modified organisms, and irrigation systems, weather is still a key factor in agricultural productivity. The effect of climate on agriculture is related to variabilities in local climates rather than in global climate patterns. The earth's average surface temperature has increased by 0.83 °C since 1880. Consequently, any assessment has to individually consider each local area.

Agriculture and fisheries are highly dependent on specific climate conditions. Trying to understand the overall effect of climate change on our food supply can be difficult. Increases in temperature and carbon dioxide ($CO_2$) can be beneficial for some crops in some places. But to realize these benefits, nutrient levels, soil moisture, water availability, and other conditions must also be met. Changes in the frequency and severity of droughts and floods could pose challenges for farmers. Meanwhile, warmer water temperatures are likely to cause the habitat ranges of many fish and shellfish species to shift, which could disrupt ecosystems. Overall, climate change could make it more difficult to grow crops, raise animals, and catch fish in the same ways and same places as we have done in the past. The effects of climate change also need to be considered along with other evolving factors that affect agricultural production, such as changes in farming practices and technology.

The Intergovernmental Panel on Climate Change (IPCC) has produced several reports that have assessed the scientific literature on climate change. The IPCC Third Assessment Report [1], [2], published in 2001, concluded that the poorest countries would be hardest hit, with reductions in crop yields in most tropical and sub-tropical regions due to decreased water availability, and new or changed insect pest incidence. In Africa and Latin America, many rainfed crops are near their maximum temperature tolerance, so that yields are likely to fall sharply for even small climate changes; falls in agricultural productivity of up to 30% over the 21$^{st}$ century are projected. Marine life and the fishing industry will also be severely affected in some places.

Climate change induced by increasing greenhouse gases is likely to affect crops differently from region to region. More favourable effects on yield tend to depend

to a large extent on realization of the potentially beneficial effects of carbon dioxide on crop growth and increase of efficiency in water use. Decrease in potential yields is likely to be caused by shortening of the growing period, decrease in water availability and poor vernalization.

Most agronomists believe that agricultural production will be mostly affected by the severity and pace of climate change, not so much by gradual trends in climate. If change is gradual, there may be enough time for biota adjustment. Rapid climate change, however, could harm agriculture in many countries, especially those which are already suffering from poor soil and climate conditions, because there is less time for optimum natural selection and adaption.

But it still remains unknown how exactly climate change may affect farming and food security, in part because the role of farmer behaviour is poorly captured by crop-climate models. For instance, the socio-economic context of farming may play a huge role in determining whether a drought has a major or an insignificant impact on crop production. In some cases, even minor droughts may have big impacts on food security, while in other cases even relatively large weather related problems may be adapted to without much hardship.

## II. PROBABLE IMPACTS ON AGRICULTURE

Researchers at the Overseas Development Institute [3] have investigated the potential impacts climate change could have on agriculture, and how this would affect attempts at alleviating poverty in the developing world. They argued that the effects from moderate climate change are likely to be mixed for developing countries. However, the vulnerability of the poor in developing countries to short term impacts from climate change, notably the increased frequency and severity of adverse weather events is likely to have a negative impact. This, they say, should be taken into account when defining agricultural policy. Fig. 1 illustrates some of the effects global warming will have on agriculture.

So far, the effects of regional climate change on agriculture have been relatively limited. Changes in crop phenology provide important evidence of the response to recent regional climate change. Phenology is the study of natural phenomena that recur periodically, and how these phenomena relate to climate and seasonal changes.

Droughts have been occurring more frequently because of global warming and they are expected to become more frequent and intense in Africa, Southern Europe, Middle East, and many parts America, Australia, and South-East Asia. The impacts may be aggravated because of increased water demand, population growth, urban expansion, and environmental protection efforts in many areas. Droughts result in crop failures and loss of pasture grazing land for livestock.

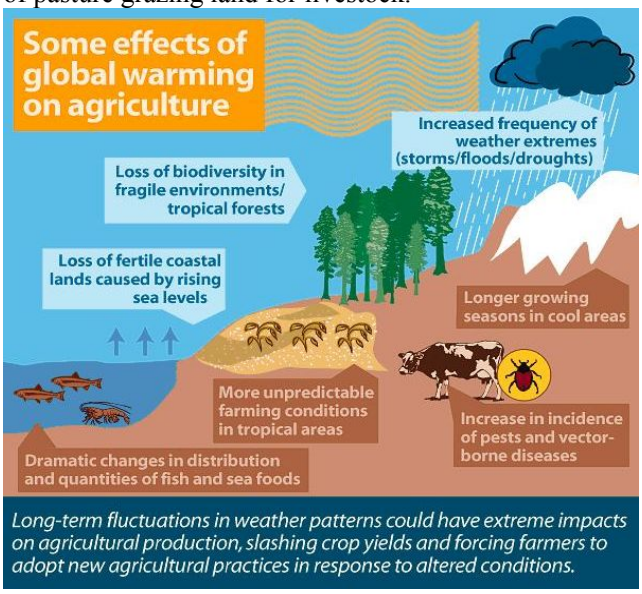


Fig. 1: Some effects of global warming on agriculture [4]

Changes in temperature, amount of carbon dioxide ($CO_2$), and the frequency and intensity of extreme weather could have significant impacts on crop yields. Warmer temperatures may make many crops grow more quickly, but warmer temperatures could also reduce yields. Crops tend to grow faster in warmer conditions. However, for some crops (such as grains), faster growth reduces the amount of time that seeds have to grow and mature. This can reduce yields (i.e., the amount of crop produced from a given amount of land). For any particular crop, the effect of increased temperature will depend on the crop's optimal temperature for growth and reproduction. In some areas, warming may benefit the types of crops that are typically planted there. However, if warming exceeds a crop's optimum temperature, yields can decline.

- Higher $CO_2$ levels can increase yields. The yields for some crops, like wheat and soybeans, could increase by 30% or more under a doubling of $CO_2$ concentrations. The yields for other crops, such as corn, exhibit a much smaller response (less than 10% increase). However, some factors may counteract these potential increases in yield. For example, if temperature exceeds a crop's optimal level or if sufficient water and nutrients are not available, yield increases may be reduced or reversed.

- More extreme temperature and precipitation can prevent crops from growing. Extreme events, especially floods and droughts, can harm crops and reduce yields.

- Dealing with drought could become a challenge in areas where summer temperatures are projected to increase and precipitation is projected to decrease. As water supplies are reduced, it may be more difficult to meet water demands.

- Many weeds, pests and fungi thrive under warmer temperatures, wetter climates, and increased $CO_2$ levels. This would cause new problems for farmers' crops previously unexposed to these species. Moreover, increased use of pesticides and fungicides may negatively affect human health.

### *A. Soil Processes*

The potential for soils to support agriculture and distribution of land use will be influenced by changes in soil water balance. Increase in soil water deficits i.e. dry soils become drier, therefore increased need for irrigation but could improve soil workability in wetter regions and diminish poaching and erosion risk.

### *B. Growing Period of Crops*

Duration of crop growth cycles are above all, related to temperature. An increase in temperature will speed up development. In the case of an annual crop, the duration between sowing and harvesting will shorten (for example, the duration in order to harvest corn could shorten between one and four weeks). The shortening of such a cycle could have an adverse effect on productivity.

### *C. Crop Growth*

Carbon dioxide is essential to plant growth. Rising $CO_2$ concentration in the atmosphere can have both positive and negative consequences. Increased $CO_2$ is expected to have positive physiological effects by increasing the rate of photosynthesis. Currently, the amount of carbon dioxide in the atmosphere is 380 parts per million. In comparison, the amount of oxygen is 210,000 ppm. This means that often plants may be starved of carbon dioxide as the enzyme that fixes $CO_2$, RuBisCo, also fixes oxygen in the process of photorespiration. The effects of an increase in carbon dioxide would be higher on C3 crops (such as wheat) than on C4 crops (such as maize), because the former is more susceptible to carbon dioxide shortage. Studies have shown that increased $CO_2$ leads to fewer stomata developing on plants which leads to reduced water usage. Under optimum conditions of temperature and humidity, the yield increase could reach 36%, if the levels of carbon dioxide are doubled. Further, few studies have looked at the impact of elevated carbon dioxide concentrations on whole farming systems. Most models study the relationship between $CO_2$ and productivity in isolation from other factors associated with climate change, such as an increased frequency of extreme weather events, seasonal shifts, and so on.

### *D. Crop Quality*

Studies have shown that higher $CO_2$ levels lead to reduced plant uptake of nitrogen (and a smaller number showing the same for trace elements such as zinc) resulting in crops with lower nutritional value. This would primarily impact on populations in poorer countries less able to compensate by eating more food, more varied diets, or possibly taking supplements. Reduced nitrogen content in grazing plants has also been shown to reduce animal productivity in sheep, which depend on microbes in their gut to digest plants, which in turn depend on nitrogen intake.

### *E. Erosion and Soil 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 precipitation would probably result in greater risks of erosion, whilst 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.

### *F. Pests and Diseases*

Global warming would cause an increase in rainfall in some areas, which would lead to an increase of atmospheric humidity and the duration of the wet seasons. Combined with higher temperatures, these could favour the development of fungal diseases. Similarly, because of higher temperatures and humidity, there could be an increased pressure from insects and disease vectors.

### *G. Adaptation Strategies*

Adaptation strategies are short and long-term changes to human activities that respond to the effects of changes in climate. In agriculture, adaptation will require cost-effective investments in water

infrastructure, emergency preparation for and response to extreme weather events, development of resilient crop varieties that tolerate temperature and precipitation stresses, and new or improved land use and management practices.

## III. RESEARCH STUDIES

As part of the IPCC's Fourth Assessment Report, Schneider et al. [5] projected the potential future effects of climate change on agriculture. With low to medium confidence, they concluded that for about 1 to 3 °C global mean temperature increase (by 2100, relative to the 1990–2000 average level), there would be productivity decreases for some cereals in low latitudes, and productivity increases in high latitudes. Most of the studies on global agriculture assessed by Schneider et al. [5] had not incorporated a number of critical factors, including changes in extreme events, or the spread of pests and diseases. Studies had also not considered the development of specific practices or technologies to aid adaptation to climate change.

The US National Research Council [6] assessed the literature on the effects of climate change on crop yields and stressed the uncertainties in their projections of changes in crop yields. Their central estimates of changes in crop yields are shown in Fig. 2 and Fig. 3. Actual changes in yields may be above or below these central estimates. US NRC [6] also provided an estimated "likely" range of changes in yields. "Likely" means a greater than 67% chance of being correct, based on expert judgement.

The Indian Agricultural Research Institute [7] examined the vulnerability of agricultural production to climate change, with the objective of determining differences in climate change impacts on agriculture by region and by crop. The predicted changes to agriculture vary greatly by region and crop. Findings for wheat and rice are reported here:

- The study found that increases in temperature (by about 2ºC) reduced potential grain yields in most places. Regions with higher potential productivity (such as northern India) were relatively less impacted by climate change than areas with lower potential productivity (the reduction in yields was much smaller).

- Climate change is also predicted to lead to boundary changes in areas suitable for growing certain crops.

- Reductions in yields as a result of climate change are predicted to be more pronounced for rain fed crops (as opposed to irrigated crops) and under limited water supply situations because there are no coping mechanisms for rainfall variability.

- The difference in yield is influenced by baseline climate. In sub tropical environments, the decrease in potential wheat yields ranged from 1.5 to 5.8%, while in tropical areas the decrease was relatively higher, suggesting that warmer regions can expect greater crop losses.

Nelson et al. [8] presented research results that quantify the climate-change impacts mentioned above, assesses the consequences for food security, and estimates the investments that would offset the negative consequences for human well-being. This analysis brings together, for the first time, detailed modeling of crop growth under climate change with insights from an extremely detailed global agriculture model, using two climate scenarios to simulate future climate. The results of the analysis suggest that agriculture and human well-being will be negatively affected by climate change:

- In developing countries, climate change will cause yield declines for the most important crops. South Asia will be particularly hard hit.

- Climate change will have varying effects on irrigated yields across regions, but irrigated yields for all crops in South Asia will experience large declines.

- Climate change will result in additional price increases for the most important agricultural crops - rice, wheat, maize, and soybeans. Higher feed prices will result in higher meat prices. As a result, climate change will reduce the growth in meat consumption slightly and cause a more substantial fall in cereals consumption.

Calorie availability in 2050 will not only be lower than in the no - climate-change scenario - it will actually decline relative to 2000 levels throughout the developing world.

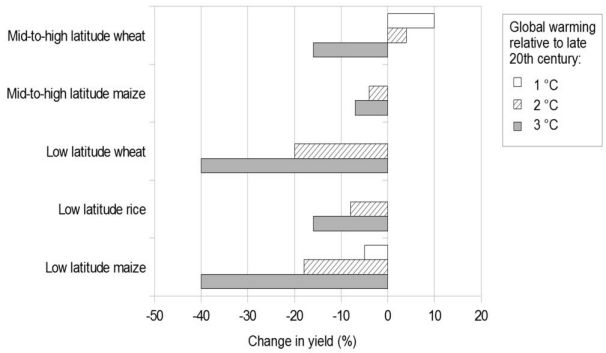


Fig. 2: Projected changes in crop yields at different latitudes with global warming

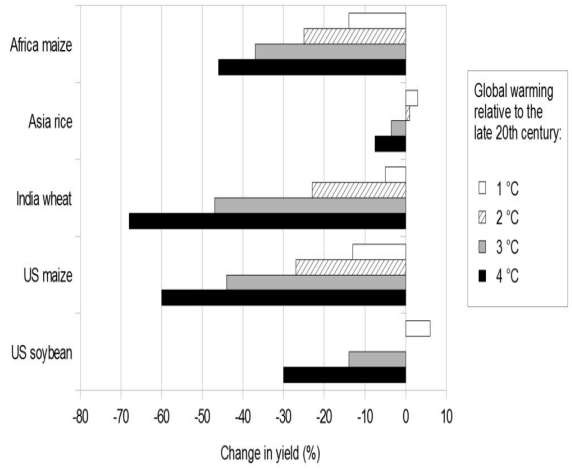


Fig. 3: Projected changes in yields of selected crops with global warming

- By 2050, the decline in calorie availability will increase child malnutrition by 20 percent relative to a world with no climate change. Climate change will eliminate much of the improvement in child malnourishment levels that would occur with no climate change.

## IV. CONCLUDING REMARKS

In the long run, the climatic change could affect agriculture in several ways:

- *Productivity*, in terms of quantity and quality of crops
- *Agricultural practices*, through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers
- *Environmental effects*, in particular in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of crop diversity
- *Rural space*, through the loss and gain of cultivated lands, land speculation, land renunciation, and hydraulic amenities
- *Adaptation*, organisms may become more or less competitive, as well as humans may develop urgency to develop more competitive organisms, such as flood resistant or salt resistant varieties of rice.

Scenarios are used in order to estimate climate changes effects on crop development and yield. Each scenario is defined as a set of meteorological variables, based on generally accepted projections. For example, many models are running simulations based on doubled carbon dioxide projections, temperatures raise ranging from 1 °C up to 5 °C, and with rainfall levels an increase or decrease of 20%. Other parameters may include humidity, wind, and solar activity. Scenarios of crop models are testing farm-level adaptation, such as sowing date shift, climate adapted species (vernalisation need, heat and cold resistance), irrigation and fertilizer adaptation, resistance to disease. Most developed models are about wheat, maize, rice and soybean.

Models for climate behaviour are frequently inconclusive. In order to further study effects of global warming on agriculture, other types of models, such as crop development models, yield prediction, quantities of water or fertilizer consumed, can be used. Such models condense the knowledge accumulated of the climate, soil, and effects observed of the results of various agricultural practices. They thus could make it possible to test strategies of adaptation to modifications of the environment.

Because these models are necessarily simplifying natural conditions (often based on the assumption that weeds, disease and insect pests are controlled), it is not clear whether the results they give will have an in-field reality. However, some results are partly validated with an increasing number of experimental results.

Due to the complex interaction of climate impacts, combined with varying irrigation techniques, regional factors, and differences in crops, the detailed impacts of these factors need to be investigated further. Specific recommendations for further research include:

- Precision in climate change prediction with higher resolution on spatial and temporal scales;
- Linking of predictions with agricultural production systems to suggest suitable options for sustaining agricultural production;
- Preparation of a database on climate change impacts on agriculture;
- Evaluation of the impacts of climate change in selected locations; and
- Development of models for pest population dynamics.

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