

Climate Change and its Impact on Agriculture

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Abstract- Global climate change is a change in the long-term weather patterns that characterize the regions of the world. The term "weather" refers to the short-term (daily) changes in temperature, wind, and/or precipitation of a region (Merritts *et al.* 1998). In the long run, the climatic change could affect agriculture in several ways such as quantity and quality of crops in terms of productivity, growth rates, photosynthesis and transpiration rates, moisture availability etc. Climate change is likely to directly impact food production across the globe. Increase in the mean seasonal temperature can reduce the duration of many crops and hence reduce the yield. In areas where temperatures are already close to the physiological maxima for crops, warming will impact yields more immediately (IPCC, 2007). Drivers of climate change through alterations in atmospheric composition can also influence food production directly by its impacts on plant physiology. The consequences of agriculture's contribution to climate change, and of climate change's negative impact on agriculture, are severe which is projected to have a great impact on food production and may threaten the food security and hence, require special agricultural measures to combat with.

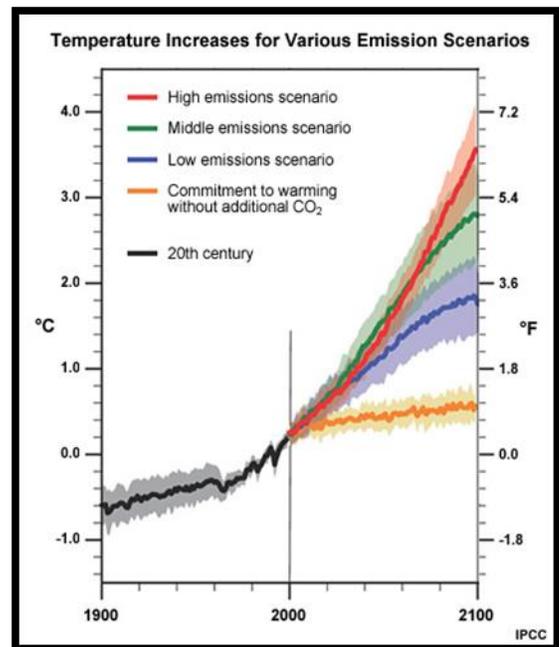
Index Terms- Climate change, Greenhouse Effect, Greenhouse gases (GHGs), Global Warming Potential (GWP), Inter governmental Panel on Climate Change (IPCC), parts per million (ppm).

I. INTRODUCTION

Climate change is any significant long-term change in the expected patterns of average weather of region (or the whole Earth) over a significant period of time. It is about non-normal variations to the climate, and the effects of these variations on other parts of the Earth. These changes may take tens, hundreds or perhaps millions of year. But increased in anthropogenic activities such as industrialization, urbanization, deforestation, agriculture, change in land use pattern etc. leads to emission of green house gases due to which the rate of climate change is much faster. Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric CO₂ concentrations. There are three ways in which the Greenhouse Effect may be important for agriculture. First, increased atmospheric CO₂ concentrations can have a direct effect on the growth rate of crop plants and weeds. Secondly, CO₂-induced changes of climate may alter levels of temperature, rainfall and sunshine that can influence plant and animal productivity. Finally, rises in sea level may lead to loss of farmland by inundation and increasing salinity of groundwater in coastal areas.

The greenhouse effect is a natural process that plays a major part in shaping the earth's climate. It produces the relatively warm and hospitable environment near the earth's surface where humans and other life-forms have been able to develop and prosper. However, the increased level of greenhouse gases (GHGs) (carbon dioxide (CO₂), water vapor (H₂O), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆) etc) due to anthropogenic activities has contributed to an overall increase of the earth's temperature, leading to a global warming. The average global surface temperature have increased by 0.74 °C since the late 19th Century and is expected to increase by 1.4 °C - 5.8 °C by 2100 AD with significant regional variations (IPCC, 2007). The atmospheric CO₂ concentration has increased from 280 ppm to 395 ppm, CH₄ concentration increased from 715 ppb to 1882 ppb and N₂O concentration from 227 ppb to 323 ppb from the year 1750 and 2012. The Global Warming Potential (GWP) of these gases i.e, CO₂, CH₄ and N₂O are 1, 25 and 310 respectively.

II. GLOBAL SCENARIO OF CLIMATE CHANGE



Source: IPCC, 2007.

Projected scenarios of global warming indicate that the global average surface temperature could rise by 1.4 to 5.8°C by 2100. The projected rate of warming is unprecedented during last 10,000 years.

All climate models indicate a rising trend in temperature. Precipitation pattern has changed with decreased rainfall over south and south-east Asia. More intense and longer droughts have occurred since 1970s. Perpetual snow cover has declined on both area and depth of snow cover. Global mean sea level is projected to rise by 0.18 to 0.59 m by the end of the century.

Six of the 10 countries most vulnerable to climate change are in the Asia-Pacific. Bangladesh tops the list followed by India, Nepal, the Philippines, Afghanistan and Myanmar. In Bangladesh, for example, about one-fifth of the nation's population would be displaced as a result of the farmland loss estimated for a 1.5 m sea-level rise. The Maldives Islands in the Indian Ocean would have one-half of their land area inundated with a 2 m rise in sea level.

III. INDIAN SCENARIO OF CLIMATE CHANGE

The warming may be more pronounced in the northern parts of India. The extremes in maximum and minimum temperatures are expected to increase under changing climate, few places are expected to get more rain while some may remain dry. Leaving Punjab and Rajasthan in the North West and Tamil Nadu in the South, which show a slight decrease on an average a 20 per cent rise in all India summer monsoon rainfall over all states are expected. Number of rainy days may come down (e.g. MP) but the intensity is expected to rise at most of the parts of India (e.g. North East). Gross per capita water availability in India will decline from 1820 m³/yr in 2001 to as low as 1140 m³/yr in 2050.

Corals in Indian Ocean will be soon exposed to summer temperatures that will exceed the thermal thresholds observed over the last 20 years. Annual bleaching of corals will become almost a certainty from 2050. Currently the districts of Jagatsinghpur and Kendrapara in Odisha; Nellore and Nagapattinam in Tamilnadu; and Junagadh and Porabandar districts in Gujarat are the most vulnerable to impacts of increased intensity and frequency of cyclones in India (NATCOM, 2004). The past observations on the mean sea level along the Indian coast show a long-term (100 year) rising trend of about 1.0 mm/year. However, the recent data suggests a rising trend of 2.5 mm/year in sea level along Indian coastline. The sea surface temperature adjoining India is likely to warm up by about 1.5–2.0°C by the middle of this century and by about 2.5–3.5°C by the end of the century. A 1 meter sea-level rise is projected to displace approximately 7.1 million people in India and about 5764 sq km of land area will be lost, along with 4200 km of roads (NATCOM, 2004).

Over 50% of India's forests are likely to experience shift in forest types, adversely impacting associated biodiversity, regional climate dynamics as well as livelihoods based on forest products. Even in a relatively short span of about 50 years, most of the forest biomass in India seems to be highly vulnerable to the projected change in climate. Further, it is projected that by 2085, 77% and 68% of the forested grids in India are likely to experience shift in forest types.

IV. CROP RESPONSES TO EXPECTED CLIMATE CHANGE FACTORS

Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric CO₂ concentrations which may affect on yield (both quality and quantity), growth rates, photosynthesis and transpiration rates, moisture availability, through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers etc. Environmental effects such as frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, land availability, reduction of crop diversity may also affect agricultural productivity.

An atmosphere with higher CO₂ concentration would result in higher net photosynthetic rates (Cure & Acock 1986, Allen et al. 1987). Higher CO₂ concentrations may also reduce transpiration (i.e. water loss) as plants reduce their stomatal apertures, the small openings in the leaves through which CO₂ and water vapor are exchanged with the atmosphere. The reduction in transpiration could be 30% in some crop plants (Kimball 1983). However, stomatal response to CO₂ interacts with many environmental (temperature, light intensity) and plant factors (e.g. age, hormones) and, therefore, predicting the effect of elevated CO₂ on the responsiveness of stomata is still very difficult (Rosenzweig & Hillel 1995). For every 75 ppm increase in CO₂ concentration rice yields will increase by 0.5 t/ha, but yield will decrease by 0.6 t/ha for every 1 °C increase in temperature (Sheehy et al., 2005). CO₂ enrichment have generally shown significant increases in rice biomass (25–40%) and yields (15–39%) at ambient temperature, but those increases tended to be offset when temperature was increased along with rising CO₂ (Ziska et al., 1996a,b; Moya et al., 1998). Yield losses caused by concurrent increases in CO₂ and temperature are primarily caused by high-temperature-induced spikelet sterility (Matsui et al., 1997a). Increased CO₂ levels may also cause a direct inhibition of maintenance respiration at night temperatures higher than 21°C (Baker et al., 2000). In rice, extreme maximum temperature is of particular importance during 3 flowering which usually lasts two to three weeks. Exposure to high temperature for a few hours can greatly reduce pollen viability and, therefore, cause yield loss. Spikelet sterility is greatly increased at temperatures higher than 35 °C (Osada et al., 1973; Matsui et al., 1997b) and enhanced CO₂ levels may further aggravate this problem, possibly because of reduced transpirational cooling (Matsui et al., 1997a).

A key mechanism of high temperature-induced floret sterility in rice is the decreased ability of the pollen grains to swell, resulting in poor thecae dehiscence (Matsui et al., 2000). Significant genotypic variation in high-temperature induced floret sterility exists. Variation in solar radiation, increased maintenance respiration losses or differential effects of night vs. day temperature on tillering, leaf-area expansion, stem elongation, grain filling, and crop phenology have been proposed as possible causes (Peng et al., 2004; Sheehy et al., 2005). In a recent climate chamber study, there was first evidence of possible genotypic variation in resistance to high night temperatures (Counce et al., 2005) High CO₂ levels and/or temperature are likely to affect crop development rates.

Predicted effects of climate change on agriculture over the next 50 years

Climatic element	Expected changes by 2050's	Confidence prediction	in Effects on agriculture
CO ₂	Increase from 360 ppm to 450 - 600 ppm (2005 levels now at 379 ppm)	Very high	Good for crops: increased photosynthesis; reduced water use
Sea level rise	Rise by 10 -15 cm Increased in south and offset in north by natural subsistence/rebound	Very high	Loss of land, coastal erosion, flooding, salinisation of groundwater
Temperature	Rise by 1-2°C. Winters warming more than summers. Increased frequency of heat waves	High	Faster, shorter, earlier growing seasons, range moving north and to higher altitudes, heat stress risk, increased evapotranspiration
Precipitation	Seasonal changes by ± 10%	Low	Impacts on drought risk' soil workability, water logging irrigation supply, transpiration
Storminess	Increased wind speeds, especially in north. More intense rainfall events.	Very low	Lodging, soil erosion, reduced infiltration of rainfall
Variability	Increases across most climatic variables. Predictions uncertain	Very low	Changing risk of damaging events (heat waves, frost, droughts floods) which effect crops and timing of farm operations

Source: Climate change and Agriculture, MAFF (2000)

Warming will accelerate many microbial processes in the soil-floodwater system, with consequences for the C and N cycle. Crop residue decomposition patterns may change. Increased soil temperature may also lead to an increase in autotrophic CO₂ losses from the soil caused by root respiration, root exudates, and fine-root turnover. Climate change impacts will also impact on rice production through rising sea level rise. Most studies project decreased yields in non-irrigated wheat and in rice, and a loss in farm-level net revenue between 9% and 25% for a temperature increase of 2–3.5°C. Aggarwal and Mall (2002) observed that a 2 °C increase resulted in a 15–17% decrease in grain yield of rice and wheat. Fungal and bacterial pathogens are also likely to increase in severity in areas where precipitation increases. Under warmer and more humid conditions cereals would be more prone to outbreaks of pest and diseases thereby reducing yield.

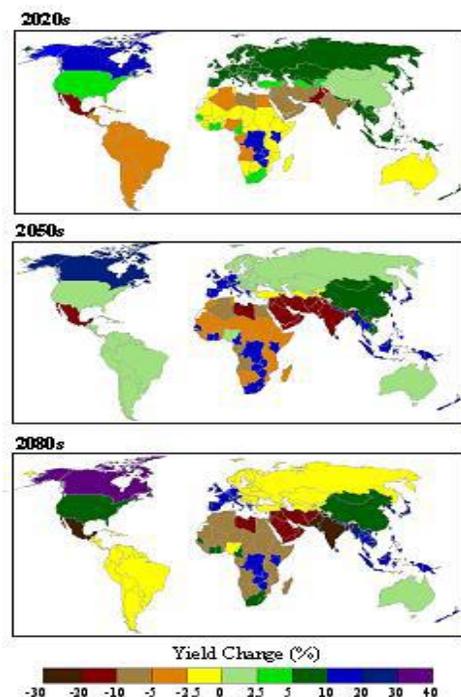
4.1 IMPACT OF CLIMATE CHANGE ON WORLD'S AGRICULTURE

Climate change is likely to directly impact on food production across the globe. Increase in the mean seasonal temperature can reduce the duration of many crops and hence reduce final yield. In areas where temperatures are already close to the physiological maxima for crops, warming will impact yields more immediately (IPCC, 2007).

World agriculture faces a serious decline within this century due to global warming. Overall, agricultural productivity for the entire world is projected to decline between 3 and 16 % by 2080. Developing countries, many of which have a average temperatures that are already near or above crop tolerance levels, are predicted to suffer an average 10 to 25% decline in agricultural productivity the 2080s. Rich countries, which have

typically lower average temperatures, will experience a much milder or even positive average effect, ranging from a 8% increase in productivity to a 6% decline. Individual developing countries face even larger declines. India, for example, could see a drop of 30 to 40%.

Fig. 1 Results of models showing possible crop yields in the future



The figure shows the results obtained using the Hadley climate model for the years 2020, 2050 and 2080. The maps show that increased temperatures in many parts of Africa will reduce food production. The decrease in rainfall in Australia will reduce crop yields but this decline can be overcome by irrigation in some cases. The increase in rainfall combined with a moderate increase in temperatures in North America may benefit food production. The burden of climate change is likely to fall disproportionately on the poorer countries of the world.

To interpret the maps we have to remember that the results obtained depend on climate, the effect of CO₂ levels on crop growth and changes in socioeconomic conditions. For example, in developed countries lower rainfall levels can be overcome through irrigation but these technological solutions are not necessarily possible in less developed countries.

4.2 IMPACT OF CLIMATE CHANGE ON INDIA'S AGRICULTURE

India's agriculture is more dependent on monsoon from the ancient periods. Any change in monsoon trend drastically affects agriculture. Even the increasing temperature is affecting the Indian agriculture. In the Indo-Gangetic Plain, these pre-monsoon changes will primarily affect the wheat crop (>0.5°C increase in time slice 2010-2039; IPCC 2007). In the states of Jharkhand, Odisha and Chhattisgarh alone, rice production losses during severe droughts (about one year in five) average about 40% of total production, with an estimated value of \$800 million (Pandey, 2007).

Increase in CO₂ to 550 ppm increases yields of rice, wheat, legumes and oilseeds by 10-20%. A 1°C increase in temperature may reduce yields of wheat, soybean, mustard, groundnut, and potato by 3-7%. Much higher losses at higher temperatures. Productivity of most crops to decrease only marginally by 2020 but by 10-40% by 2100 due to increases in temperature, rainfall variability, and decreases in irrigation water. The major impacts of climate change will be on rain fed or un-irrigated crops, which is cultivated in nearly 60% of cropland. A temperature rise by 0.5°C in winter temperature is projected to reduce rain fed wheat yield by 0.45 tonnes per hectare in India (Lal et al., 1998). Possibly some improvement in yields of chickpea, rabi maize, sorghum and millets; and coconut in west coast. Less loss in potato, mustard and vegetables in north-western India due to reduced frost damage. Increased droughts and floods are likely to increase production variability

Recent studies done at the Indian Agricultural Research Institute indicate the possibility of loss of 4 – 5 million tons in wheat production in future with every rise of 1°C temperature throughout the growing period. Rice production is slated to decrease by almost a tonne/hectare if the temperature goes up by 2 °C. In Rajasthan, a 2°C rise in temperature was estimated to reduce production of Pearl Millet by 10-15%. If maximum and minimum temperature rises by 3°C and 3.5°C respectively, then Soyabean yields in M.P will decline by 5% compared to 1998. Agriculture will be worst affected in the coastal regions of Gujarat and Maharashtra, as fertile areas are vulnerable to inundation and salinisation.

V. AGRICULTURAL PRODUCTIVITY AND FOOD SECURITY

Food security is both directly and indirectly linked with climate change. Any alteration in the climatic parameters such as temperature and humidity which govern crop growth will have a direct impact on quantity of food produced. Indirect linkage pertains to catastrophic events such as flood and drought which are projected to multiply as a consequence of climate change leading to huge crop loss and leaving large patches of arable land unfit for cultivation and hence threatening food security. The net impact of food security will depend on the exposure to global environmental change and the capacity to cope with and recover from global environmental change. On a global level, increasingly unpredictable weather patterns will lead to fall in agricultural production and higher food prices, leading to food insecurity.

Food insecurity could be an indicator for assessing vulnerability to extreme events and slow-onset changes. This impact of global warming has significant consequences for agricultural production and trade of developing countries as well as an increased risk of hunger. The number of people suffering from chronic hunger has increased from under 800 million in 1996 to over 1 billion recently. United Nations population data and projections (UN 2009) show the global population reaching 9.1 billion by 2050, an increase of 32 per cent from 2010. The world's population is expected to grow by 2.2 billion in the next 40 years to 2050, and a significant part of the additional population will be in countries that have difficulties feeding themselves. Preliminary estimates for the period up to 2080 suggest a decline of some 15–30 per cent of agricultural productivity in the most climate-change-exposed developing country regions – Africa and South Asia.

Even the IPCC, scarcely alarmist, says 0.5 °C rise in winter temperature would reduce wheat yield by 0.45 tons per hectare in India. Rice and wheat have a total share in total food grain production in India. Any change in rice and wheat yields may have a significant impact on food security of the country. And this when Indian agriculture has already pushed into crisis, and 2.56 lakh farmers have committed suicide since 1995.

According to A K Singh, deputy director-general (natural resource management) of the Indian Council of Agricultural Research (ICAR), medium-term climate change predictions have projected the likely reduction in crop yields due to climate change at between 4.5 and 9 per cent by 2039. The long run predictions paint a scarier picture with the crop yields anticipated to fall by 25 per or more by 2099. With 27.5% of the population still below the poverty line, reducing vulnerability to the impacts of climate change is essential. Indian food production must increase by 5 million metric tons per year to keep pace with population increase and ensure food security. Coping with the impact of climate change on agriculture will require careful management of resources like soil, water and biodiversity. To cope with the impacts of climate change on agriculture and food production, India will need to act at the global, regional, national and local levels.

VI. CLIMATE CHANGE – MITIGATION AND ADAPTATION IN AGRICULTURE

1. Assist farmers in coping with current climatic risks by providing value-added weather services to farmers. Farmers can adapt to climate changes to some degree by shifting planting dates, choosing varieties with different growth duration, or changing crop rotations.
2. An Early warning system should be put in place to monitor changes in pest and disease outbreaks. The overall pest control strategy should be based on integrated pest management because it takes care of multiple pests in a given climatic scenario.
3. Participatory and formal plant breeding to develop climate-resilient crop varieties that can tolerate higher temperatures, drought and salinity.
4. Developing short-duration crop varieties that can mature before the peak heat phase set in.
5. Selecting genotype in crops that have a higher per day yield potential to counter yield loss from heat-induced reduction in growing periods.
6. Preventive measures for drought that include on-farm reservoirs in medium lands, growing of pulses and oilseeds instead of rice in uplands, ridges and furrow system in cotton crops, growing of intercrops in place of pure crops in uplands, land grading and leveling, stabilization of field bunds by stone and grasses, graded line bunds, contour trenching for runoff collection, conservation furrows, mulching and more application of Farm yard manure (FYM).
7. Efficient water use such as frequent but shallow irrigation, drip and sprinkler irrigation for high value crops, irrigation at critical stages.
8. Efficient fertilizer use such as optimum fertilizer dose, split application of nitrogenous and potassium fertilizers, deep placement, use of *neem*, *karanja* products and other such nitrification inhibitors, liming of acid soils, use of micronutrients such as zinc and boron, use of sulphur in oilseed crops, integrated nutrient management.
9. Seasonal weather forecasts could be used as a supportive measure to optimize planting and irrigation patterns.
10. Provide greater coverage of weather linked agriculture-insurance.
11. Intensify the food production system by improving the technology and input delivery system.
12. Adopt resource conservation technologies such as no-tillage, laser land leveling, direct seeding of rice and crop diversification which will help in reducing in the global warming potential. Crop diversification can be done by growing non-paddy crops in rain fed uplands to perform better under prolonged soil moisture stress in kharif.
13. Develop a long-term land use plan for ensuring food security and climatic resilience.
14. National grid grain storages at the household/ community level to the district level must be established to ensure local food security and stabilize prices.
15. Provide incentives to farmers for resource conservation and efficiency by providing credit to the farmers for transition to adaptation technologies.
16. Provide technical, institutional and financial support for establishment of community banks of food, forage and seed.
17. Provide more funds to strengthen research for enhancing adaptation and mitigation capacity of agriculture.

VII. CONCLUSION

Climate change, the outcome of the “Global Warming” has now started showing its impacts worldwide. Climate is the primary determinant of agricultural productivity which directly impact on food production across the globe. Agriculture sector is the most sensitive sector to the climate changes because the climate of a region/country determines the nature and characteristics of vegetation and crops. Increase in the mean seasonal temperature can reduce the duration of many crops and hence reduce final yield. Food production systems are extremely sensitive to climate changes like changes in temperature and precipitation, which may lead to outbreaks of pests and diseases thereby reducing harvest ultimately affecting the food security of the country. The net impact of food security will depend on the exposure to global environmental change and the capacity to cope with and recover from global environmental change.

Coping with the impact of climate change on agriculture will require careful management of resources like soil, water and biodiversity. To cope with the impact of climate change on agriculture and food production, India will need to act at the global, regional, national and local levels.

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