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REVIEW ARTICLE

Climate change and agriculture-mitigation and adaptations through agronomic practices

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SUMMARY : The Intergovernmental Panel on Climate Change (IPCC) has projected that the global mean surface temperature will rise by 2.0-4.5^{0}C by 2100 due to increase in carbon dioxide concentration in the atmosphere. Climatic variability is also projected to increase, leading to uncertain onset of rainfall and more frequent extreme weather events. Global warming is projected to have significant impacts on conditions affecting agriculture, including temperature, precipitation and glacial run-off. These conditions determine the carrying capacity of the biosphere to produce enough food for the human population and domesticated animals. Climate change is likely to have a significant impact on agriculture. In general, the faster is the climate changes, the greater will be the risk of damage. According to the IPCC, potential global food production is projected to increase with local average temperatures rising over a range of 1–3^{0}C, but projected to decrease over this level. Agronomic studies suggested that extensive warming could cause significant reduction in crop yields. Food security is unlikely to be threatened at the global level, but some regions are likely to experience food shortages and hunger. Water resources will be affected as precipitation and evaporation patterns change around the world. In the changing climatic scenarios, there is a need to reinvent the research strategies *i.e.* adaptations of resource conservation technologies, judicious use of available water resources, enhance value-added weather management services and also to moderate the stresses due to biotic and abiotic factors to mitigate the deleterious effects of climate change.

Key Words :
Climate change, Agronomic practices, Agricultural ecosystem

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In the recent past, human activities all over the world have exploited the natural resources to meet their needs including a disturbed ecosystem with dangerous signals of continuous global warming and climate change. In the recent past, it has become a burning issue in every part of the globe to access the climate change behaviour using past records and to predict the future expected global changes. The Inter-Governmental Panel on Climate Change (IPCC, 2007) projected an increase in global average temperature between 0.1 and 0.3^{0}C per decade. This can be compared with observed values of about 0.2^{0}C per decade, strengthening in near term projections (Iglesias, 2005). For the Indian regions, the IPCC projected 0.5 to 1.2^{0}C rise in temperature by 2020, 0.88 to 3.16^{0}C by 2050 and 1.56 to 5.44^{0}C by 2080, depending on the future development scenario. Continued green house gas emissions at or above the current rate would cause further warming by 21st century. The global atmospheric concentration of CO_2 has increased from a pre-industrial value of about 280 ppm to 387 ppm in 2010. Such impacts are more likely on fragile ecosystems like arid regions, where hot environment, low and erratic rainfall conditions prevail and the crops are sensitive to soil water (Rao and Saxton, 1995). The PRECIS 9 providing regional climate for impact studies model for India arid region predicted for an increase in annual rainfall by 10-15 per cent in the eastern fringe and 20-40 per cent in the south, but the North West will experience up to 30 per cent reduction in the rainfall. The PRECIS model for India also showed an increase in an annual mean surface temperature by 3 to 5^{0}C under A_2 scenario and 2.5 to 4^{0}C under B_2 scenario, with warming more pronounced in the northern parts of India by the end of century. Warming is more in winter (December to February) and post monsoon (October-November) seasons compared to southwest monsoon (June-September) seasons (Kumar *et al.*, 2006). These climate changes are expected to alter the natural ecosystem in many parts of the globe.

Agricultural ecosystems are subject to severe climatic inter-annual variability and these systems will become more vulnerable under the expected scenarios of climate. It will also cause deleterious effects on crops, biodiversity, water resources and many more aspects of the living components of the earth's ecosystems.

Causes of climate change and global warming:

Inter-Governmental Penal on Climate Change (IPCC, 1996) referred climate change as a movement in climate system because of internal changes within the climate system or due to the interaction of its components or because of changes in external forcing either by natural or anthropogenic activities.

Natural causes:

The natural causes of climate change include volcanic eruptions where in sulfur dioxide is injected in the upper atmosphere reflecting sunlight back to the upper atmosphere and prevent the solar radiation or energy to reach earth surface. Natural oscillation of the ocean currents influences the atmospheric circulation. Other natural causes are the fluctuations in the sun's intensity which can influence temperature on the earth if they occur for longer periods of time *i.e.* a time scale above 10,000 years.

Anthropogenic causes:

The anthropogenic causes are more serious for climate change activities. These are contributed by the activities of the human beings with the intention of improving the living standards and urbanization. The increase in greenhouse gases concentration has been identified as the primary cause of global warming since 1950. Carbondioxide, nitrogen, nitrous oxide, ozone, sulphur oxide, methane other gases and water vapours are prominent green house gases which allow the shortwave radiations from the sun to pass through but do not allow the long wave radiation to escape from the earth to the outer atmosphere thus increasing the temperature of the earth and causing the global warming. The concentration of these gases increased in the atmosphere due to the burning of fossil fuel, methane emission from agriculture, livestock and industries. Other factors which may cause the increase in these gases could be changed in the land use patterns, deforestation and elevated use of the inorganic fertilizers in the agriculture.

Green house gas effect:

Greenhouse gases are global in their effect upon the atmosphere. The primary greenhouse gases, unlike many local air pollutants–carbon monoxide, oxides of nitrogen and volatile organic compounds, are considered stock pollutants. A stock pollutant is one that has a long lifetime in the atmosphere, therefore can accumulate over time. Stock air pollutants are also generally well mixed in the atmosphere. These characters of the greenhouse gases imply that they should be addressed on a global scale. The anthropogenic emissions of green house gases results from many of the industrial, transportation, agricultural and other activities that take place in each country. Kyoto protocol on climate change in 1997 emerged as an global issue because of its deeper relationship with agricultural production activities (Rogenzweig and Hillel, 1998) as they contribute to build up greenhouse gases particularly methane, nitrous oxide ,water vapour, carbon dioxide and halocarbons. IPCC (2001) have reported enormous increase in the concentration of these gases over the last 200 years. In the US, approximately 6.6 tons of greenhouse gases are emitted per person per year.

Climate change projections for India:

Studies conducted in the country have shown that the surface air temperatures in India are going up at the rate of 0.4^{0}C per hundred years, particularly during the post-monsoon and winter season. Models prediction showed and predicted that mean winter temperatures will increase by as much as 3.2^{0}C in the 2050s and 4.5^{0}C by 2080s, due to greenhouse gases. Summer temperatures will increase by 2.2^{0}C in the 2050s and 3.2^{0}C in the 2080s. Annual mean area averaged surface warming over the Indian sub continent is likely to range between 3.5^{0}C and 5.5^{0}C by 2080 (Lal, 2001). These projections showed more warming in winter season over the summer. The spatial distribution of surface warming suggests a mean annual rise in temperature in the north India by 3^{0}C by 2050. The study also indicated that during the winter, the surface mean air temperature could rise by 3^{0}C in Northern and Central parts while it would rise by 2^{0}C in the southern parts by same period. In case of rainfall, a marginal increase of 7-10 per cent in annual rainfall is projected over the sub continent by 2080. Nevertheless, the study suggests a fall in rainfall by 5-25 per cent in winter, while it would be a 10-15 per cent increase in summer.

The climate change projections for India used for the analysis are those reported by Cline (2007). The climate change projections are average of predictions of six general circulation models including HadCM3, CSIROMk2, CGCM2, GFDL-R30, CCSR/NIES and ECHAM4/OPYC3. Table 1 shows the region-wise and season-wise temperature and rainfall changes in India for the period 2070-2099 with reference to the base period 1960-1990. From these regional projections, state-wise climate change predictions are assessed by comparing the latitude-longitude ranges of the regions with those of the states. Besides this India specific climate change scenario, the impacts are also assessed for two illustrative uniform climate change scenarios (+2^{0}C temperature change along with+7 per cent precipitation change; and +3.5^{0}C temperature change along with +14 per cent precipitation change) that embrace the aggregate changes outlined in the fourth assessment report of IPCC (Solomon, 2007).

Climate change and agriculture:

The impact of climate change on agriculture will be one of the major deciding factors influencing the future food security of mankind on earth. Agriculture is not only sensitive to climate change but, at the same time, is one of the major drivers for climate change. Understanding the weather changes over a period of time and adjusting the management practices towards achieving better harvest is a challenge to the growth of agricultural sector as a whole.

The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops, cropping system, soils and management practices. The inter annual variations in temperature and precipitation are much higher than the predicted changes in temperature and precipitation. The crop losses may increase if the predicted climate change increases the climate variability. Different crops respond differently as the global warming will have a complex impact.

According to 4th IPCC Assessment Report (2007), the cereal yields in south Asia could drop in some areas by upto 30 per cent by 2050. According to this report, the crop productivity is projected to increase slightly at mid-to high latitudes for local mean temperature increases of up to 1-3^{0}C depending on the crop and then decrease beyond that in some regions. At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1-2^{0}C). Increase in the frequency of droughts and floods are projected to affect local crop production negatively, especially in subsistence sectors at low latitudes.

One of the specific studies conducted by Sinha and Swaminathan (1996) revealed that while mean air temperatures recorded over the wheat growing seasons in northern India were high by 1.7^{0}C over a period of 15 days (January 16 to February 1), the actual temperature rise was of the order of 2.3 to 4.5^{0}C in the major wheat producing regions of Punjab and Haryana. Studies showed that wheat yield could decrease as much as 130-150 kg/ha for each degree rise in night temperatures during reproductive period. Similarly, in case of rice, the yields could dip up to 10 per cent for every 1^{0}C increase in minimum temperature during the critical growing season. Further experiments on rice in India, reported by Sinha *et al.* (1998) showed that higher temperatures and reduced radiation associated with increased cloudiness caused spikelet sterility and reduced yields in rice to such an extent that, any increase in dry matter production as a result of CO_2 fertilization proved to be of no advantage in grain productivity.

Rice, wheat, maize, sorghum, soybean and barley are the six major crops in the world and they are grown in 40 per cent cropped area, 55 per cent of non-meat calories and over 70 per cent of animal feed (FAO, 2006). Since 1961, there is substantial increase in the yield of all the crops. The impact of warming was likely offset to be minimized to some extent, by fertilization effects of increased CO_2 levels. At the global scale, the historical temperature-yield relationships indicate that warming from 1981 to 2002 is very likely to offset some of the yield gains from technological advance, rising CO_2 and other non-climatic factors (Lobell and Field, 2007).

Kothawale and Kumar (2005) reported that while All-India mean annual temperature has shown significant warming trend of 0.05^{0}C/10 yr during the period 1901-2003, the recent period 1971-2003 has seen a relatively accelerated warming of 0.22^{0}C/10 yr, which is largely due to unprecedented warming during the last decade. Further, in a major shift, the recent period is marked with by rising temperatures during the monsoon

Table 1: Projected changes of climate in India : 2070-2099

Region	Jan.-March	April-June	July-Sep.	Oct.-Dec.
Temperature change (^{0}C)				
Northeast	4.95	4.11	2.88	4.05
Northwest	4.53	4.25	2.96	4.16
Southeast	4.16	3.21	2.53	3.29
Southwest	3.74	3.07	2.52	3.04
Precipitation change (%)				
Northeast	-9.3	20.3	21.0	7.5
Northwest	7.2	7.1	27.2	57.0
Southeast	-32.9	29.7	10.9	0.7
Southwest	22.3	32.3	8.8	8.5

Source: Cline (2007)

season, resulting in a weakened seasonal asymmetry of temperature trends reported earlier. On a regional basis, stations of southern and western India showed a rising trend of 1.06 and 0.36^{0}C/100 yr, respectively. While stations of the North Indian plains showed a falling trend of -0.38^{0}C/100 yr. The seasonal mean temperature has increased by 0.94^{0}C/100 yr for the post monsoon season and by 1.1^{0}C/100 yr for the winter season. Some of the instances of observed spatial variability in the temperature phenomena during last few years include extreme cold winter during 2002-03, wide spread prevailing drought situations during July, 2004, 20-day heat wave in A.P. during May, 2003 (Ramakrishna, 2007).

In the recent past, there are indications to suggest that there are slight shifts in the wheat growing area towards northern parts of India due to temperature rise in some parts of central India. Similar trend was also observed in case of apple production zones where some shifts to higher altitudes are observed in Himachal Pradesh as the required chilling period which influences the quality of the apple is not met in the earlier growing regions as they are now experiencing increased thermal regime.

Rosenzweig and Parry (1994) estimated the net effect of climate change on global production up to 5 per cent, but production may decrease in developing countries and increase in developed countries. Doubling CO_2 concentration may increase the photosynthetic rates by as much as 30 to 100 per cent in C_3 plants such as wheat, rise and soybean, whereas response in C_4 plants such as maize, sorghum, sugarcane, millets etc. may remain as such (IUCC, 1992)

Studies conducted by IARI, New Delhi reported a loss of 4 to 5 million tones in the overall wheat production with every 1^{0}C increase in temperature throughout the growing period of the crop. In Rajasthan, a 2^{0}C rise in temperature was estimated to reduce production of pearl millet by 10-15 per cent. Increased temperatures will impact agricultural production. Higher temperatures reduce the total duration of a crop cycle by inducing early flowering, thus shortening the 'grain fill' period. The shorter the crop cycle, the lower the yield per unit area. Increased temperature also mean increased evaporation and transpiration rates. Even a small increase of 1^{0}C could increase the rate of evaporation/transpiration by 5-15 per cent. With no rainfall to compensate, yields will be reduced. In north India, for instance, a temperature rise of 0.5^{0}C could reduce wheat yields due to heat stress by about 10 per cent if rainfall does not increase. The scientists predict that a temperature increase of 3^{0}C will result in a 15-20 per cent decrease in wheat yields, and also a decrease in rice yields. It has been reported that wheat yield declined by 5 per cent when temperature during March increased above normal by 1^{0}C under Punjab conditions. There was an increase of rice yield to the tune of 12 per cent with the projected climate change scenario (increase of temperature by 1.5^{0}C and rainfall by 2 mm at a CO_2 concentration of 460 ppm) in southern India. The projected effected of climate change on agriculture are presented in Table 2.

Although increase in carbon dioxide is likely to be beneficial to several crops, associated increase in temperatures, and increased variability of rainfall would considerably impact food production. Recent IPCC report and a few other global studies indicate a probability of 10–40 per cent loss in crop production in India with increases in temperature by 2080 – 2100.

Yields of major crops in India are projected to decline by 4.5 to 9 per cent within the next three decades (WDR, 2010), while the per capita consumption of cereals has been declining since the early 1970s.

Droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, and heat waves are known to negatively impact agricultural production, and farmers' livelihood. The projected increase in these events will result in greater

Table 2: Projected effects of climate change on agriculture over the next 50 years

Climatic element	Expected changes by 2055's	Confidence in prediction	Effects on agriculture
Temperature	Rise by 1-2^{0}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 evaporanspiration
Precipitation	Seasonal changes by $\pm$ 10 per cent	Low	Impacts on drought risk, water logging, irrigation supply, transpiration
CO_2	Increase from 360 ppm to 450-600 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
Variability	Increases across most climatic variables. Predictions uncertain	Very low	Changing risk of damaging events (heat waves, droughts, floods etc.) which effect crops and timing of farming operations

instability in food production and threaten livelihood security of farmers. Increasing glacier melt in Himalayas will affect availability of irrigation especially in the Indo-Gangetic plains, which, in turn, has large consequences on our food production.

Global warming in short-term is likely to favour agricultural production in temperate regions (largely Northern Europe, North America) and negatively impact tropical crop production (South Asia, Africa). This is likely to have consequences on international food prices and trade and hence our food security.

Pathogens and insect populations are strongly dependent upon temperature and humidity. Increases in these parameters will change their population dynamics resulting in yield loss.

The above facts emphasize the need to not only study in detail the climate change vulnerability of agriculture but also the methods of improving the adaptive capacity of agriculture to climate variability and extremes.

Projected priorities for adaptation and mitigation strategies:

Agricultural productivity is sensitive to broad classes of climate-induced effects: (i) direct effects from changes in temperature, precipitation and carbon dioxide concentrations and (ii) indirect effects through changes in soil moisture and the distribution and frequency of infestation by pests and diseases. Rice and wheat yields could decline considerably with climatic changes (IPCC, 1996; 2001).

In the changing climatic scenarios, there is a need to reinvent the research strategies *i.e.* judicious use of available water resources and also to moderate the stresses due to biotic and abiotic factors. There are some of the measures suggested for the adaptation and mitigation of deleterious effects of climate change:

Adaptation of resource conserving technologies:

There is a need to create awareness about the resource conserving technologies like zero tillage/minimum tillage, water saving techniques (bed planting, furrow planting, direct seeding of rice, integrated nutrient management to offset climate change effects. These conservation techniques have a direct linkage with the climate resilience in agriculture.

Altered agronomy of crops:

It is, however, possible for farmers and other stakeholders to adapt to a limited extent and reduce the losses. Simple adaptations such as change in planting dates, spacing, crop varieties and input management could help in reducing impacts of climate change to some extent. Alternate crops or cultivars more adapted to changed environment can further ease the pressure. For example, the Indian Agricultural Research Institute study quoted above indicates that losses in wheat production in future can be reduced from 4 – 5 million tons to 1 – 2 million tons if a large percentage of farmers could change to timely planting and changed to better adapted varieties. This change of planting would, however, need to be examined from a cropping systems perspective.

Development of micro irrigation technologies:

Micro irrigation technologies especially in the dry land areas and other areas devoid of irrigation facilities needs to be promoted for efficient water use. This will reduce the water wastage due to elevated evapotranspiration caused by climate change.

Reduction of green house gases (GHG) emission in agriculture:

The adoption of improved water saving technologies and fertilizer management in paddy could reduce the emissions of GHGs. The paddy fields under anaerobic conditions release methane a second important GHG after CO_2. In these situations, dry seeded Rice should be encouraged if possible otherwise technologies should be invented to sort out this problem. The improved management of livestock population and its diet could also assist in reducing the emissions of GHGs. Approaches to increase soil carbon such as organic manures, minimal tillage, and residue management should be encouraged. These have synergies with sustainable development as well. The use of nitrification inhibitors such as neem coated urea, and adoption of improved fertilizer placement practices need to be adopted for further GHG mitigation. There is utmost need to improve the efficiency of energy use in agriculture by using better designs of machinery, and by conservation practices.

Enhance value added weather management services:

– Develop spatially differentiated operational contingency plans for temperature and rainfall related risks, including supply management through market and non-market interventions in the event of adverse supply changes.
– Enhance research on applications of short, medium and long range weather forecasts for reducing production risks.
– Develop knowledge based decision support system for translating weather information into operational management practices. Such systems will simulate the inputs being used by the crops and tell about the best farming options under changed climatic scenarios.
– Develop pest forecasting system covering range of parameters for contingency planning and effective disease management.

Improved land use and natural resource management policies and institutions:

Adaptation to environmental change could be in the form of social aspects such as crop insurance, subsidies, and pricing policies related to water and energy. Necessary provisions need to be included in the development plans to address these issues of attaining twin objectives of containing environmental changes and improving resource use productivity. Policies should be evolved that would encourage farmers to enrich organic matter in the soil and thus improve soil health such as financial compensation/incentive for green manuring.

Reformation of national legislation and implementation of response measures:

There is a need to relook into the legislation of response measures for climate change and related issues. For example, despite a ban on paddy and wheat stubble burning, farmers violate the legislation and continue doing these activities.

Development of high temperature/drought resistant cultivars:

The shortage of water is expected in future due to the climate change patterns and elevated temperatures. This will create a drought like situation in many parts of the country. The breeding programmes should be aimed at developing such varieties of different crops having traits for temperature stress and low water requirements.

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