A REVIEW :

Implications of climate change

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SUMMARY

The Intergovernmental Panel on Climate Change has projected that the global mean surface temperature will rise by 2.0-4.5^{O}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. Rising carbon dioxide levels would also have effects, both detrimental and beneficial, on crop yields. According to 4th Assessment Report of IPCC, 2007, the 120 million to 1.2 billion people in Asia will experience increased water stress by 2020 and 185 to 981 million by 2050. The per capita water availability in India will drop from around 1900 cubic meter currently to 1000 cubic metres by 2025. According to the IPCC, potential global food production is projected to increase with local average temperatures rising over a range of 1–3^{O}C, but projected to decrease over this level.

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Worldwide, climate change and weather variability have become the topic of great concern in the recent years. Climatic change refers to long-term changes in mean temperature or precipitation as well as increased frequency of extreme climate effects that may affect the crops, cropping systems, livestock, pests and thereby threatening the food security. Global warming is becoming an universally acknowledged fact. It has likewise been accepted that climate change is largely caused by human activities and that the effects are inevitable, even if emissions of greenhouse gases (GHGs) are brought to an immediate end. There is an increasing concern that human activities may be inadvertently changing the climate of the globe through enhanced greenhouse effect, by past and continuing emissions of carbon dioxide and other green house gases which will cause the temperature of the earth surface to increase – popularly termed as global warming.

The major cause to climate change has been ascribed to the increased levels of greenhouse gases due to the uncontrolled activities such as burning of fossil fuels, increased use of refrigerants and changed land use pattern related practices. There is a general consensus that greenhouse warming would have major impact on agro-ecosystems. The atmospheric gaseous constituents which absorb thermal radiations and cause greenhouse warming include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), water vapour and chlorofluorocarbons (CFC's). The atmospheric concentration of carbon dioxide is increasing at alarming rates (1.9 ppm per year) in the recent years. The increase in mean air temperature over last 100 years (1850-1899 to 2001-2005) is 0.76^{O}C, which is influencing the agricultural production system. The Fourth Assessment Report of Intergovernmental Panel on Climate Change, IPCC (2007) concluded "there is high confidence that recent regional changes in temperature had discernible impacts on many physical and biological systems". Recent IPCC report and a few other studies indicated a

probability of 10-40 per cent loss in crop production in India with increase in temperature by the end of this century due to global warming. Now it is beyond any doubt that the planet is warming and given the fact that during the last 50 years eleven of the twelve hottest years have been recorded after 1990, the magnitude of warming and risks associated with it may be even greater than predicted before. Increased concentration of greenhouse gases like CO_2 and warming will have serious consequences like rise in sea level, increased evaporation, increased frequency of extreme events like floods, droughts and heat waves. All these events will have profound impact on crop yields and farm profits particularly in tropical and sub tropical regions where abiotic stresses are already serious constraints to crop production (Reddy and Hodges, 2000; IPCC, 2007).

Climate change and agriculture are interrelated processes, both of which take place on a global scale. 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. Rising carbon dioxide levels would also have effects, both detrimental and beneficial, on crop yields. The overall effect of climate change on agriculture depends on the balance of these effects. Assessment of the effects of global climate changes on agriculture might help properly to 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, but also by altering the earth's land cover, which can change its ability to absorb or reflect heat and light, thus, contributing to radiative forcing. Land use change such as deforestation and desertification, together with use of fossil fuels, are the major anthropogenic sources of carbon dioxide; agriculture itself is the major contributor is increasing methane and nitrous oxide concentrations in earth's atmosphere. Despite technological advances, such as improved varieties, genetically modified organisms, and irrigation systems, weather is still a key factor in agricultural productivity, as well as soil properties and natural communities. The effect of climate on agriculture is related to variabilities in local climates rather than in global climate patterns. The projected effects of climate change on agriculture are presented in Table 1.

Climate change at a glance:

Increased warming:

Eleven of the last twelve years rank among the warmest years in global surface temperature since 1850. The rate of warming averaged over the last 50 years is nearly twice that for the last 100 years. The average global temperature went up by about 0.74°C during the 20th century with the warming affecting land more than ocean areas.

There is more carbon dioxide in the atmosphere:

Carbon dioxide is the dominant contributor to current climate change and its atmospheric concentration has increased from a pre-industrial value of 278 parts-per million (ppm) to 379 in 2005.

Table 1 : 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°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 $\pm$ 10%	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

More water, but not everywhere:

More precipitation has been observed in the eastern parts of North and South America, northern Europe and northern and central Asia in recent decades. But the Sahel, the Mediterranean, southern Africa and parts of southern Asia have experienced drying. More intense and longer droughts have been observed over wider areas since the 1970s.

Sea level is rising:

The Intergovernmental Panel on Climate Change is highly confident that the rate of observed sea level increased from the 19th to 20th century, and the total 20th century rise is estimated to be 0.17 metre. Geological observations indicate that sea level rise over the previous 2,000 years was far less. The average temperature of the global ocean has increased to depths of at least 3,000 metres.

Less snow cover:

Snow cover is decreasing in most regions, particularly in spring. The maximum extent of frozen ground in the winter/spring season has decreased by about 7 per cent in the northern Hemisphere since 1900, and on average rivers that freeze to 5.8 days later than a century ago and their ice breaks up 6.5 days earlier.

Glaciers are melting:

Mountain glaciers and snow cover have declined, on average, in both hemispheres, and have contributed to sea level rise by 0.77 millimetres a year from 1993 to 2003. Shrinkage of the ice sheets of Greenland and Antarctica have contributed to a sea level rise of 0.4 millimetres a year between 1993 and 2003.

Arctic is warming:

Average Arctic temperatures increased at almost twice the global average rate in the past 100 years. Satellite data since 1978 show that the average Arctic sea ice extent has shrunk by 2.7 per cent per decade.

New projections indicate faster warming

Continued greenhouse gas emissions at or above the current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.

– The degree of warming depends on the degree of emissions: If carbon dioxide concentrations were stabilized at 550 ppm — double the pre-industrial levels — the average warming expected would likely be in the range of 2-4.5^{O}C, with the best estimate of 3^{O}C, or 5.4^{O}F. A warming of 0.2^{O}C per decade is expected for each of the next two decades for a range of scenarios that do not include deliberate reductions in greenhouse gas emissions.

– Other greenhouse gases contribute to warming and if their combined effect were equivalent to a carbon dioxide level of 650 ppm, the global climate would "likely" warm by 3.6^{O}C, while a level of 750 ppm would produce warming of 4.3^{O}C. Projections depend on factors such as economic growth, population, new technologies and other factors.

– Warmr global temperatures are already causing profound changes in many of the earth's natural systems. Approximately 20-30 per cent of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5-2.5^{O}C.

– A temperature increase of 3^{O}C during this century would have largely negative consequences for biodiversity ecosystems that produce essential goods and services, such as water and food supply.

– As a result of warmer temperatures, springtime events are occurring earlier, such as increased run-off and peak discharge in many glacier- and snow-fed rivers, "greening" of vegetation and migration and egg-laying by birds. More animal and plant species have also been observed shifting toward higher latitudes.

– More precipitation in the high latitudes: Increases in precipitation are very likely in the high latitudes while decreases are likely in most subtropical land regions.

– Model based estimates for sea-level rise due to ocean expansion and glacier melt by the end of the century (compared to 1989-1999 levels) have narrowed from previous assessments to 18-58 cm. However, larger values cannot be ruled out if recently observed movements of ice sheets were to increase as temperature rises.

– Contraction of the Greenland ice sheet is projected to contribute to sea level rise into the 22nd century and the ice sheet could face complete elimination if global average warming of 1.9-4.6^{O}C is maintained for a millennium. In that case, sea level would rise by up to 7 metres.

Implications with special reference to India:

Increased temperature:

A marginal rise in the atmospheric temperature due to climate change may seriously upset the ecological

balance. The surface air temperatures over India are going up at the rate of 0.4°C per hundred years, particularly during the post-monsoon and winter season.5 Using models, the scientists predict that mean winter temperatures will increase by as much as 3.2°C in the 2050s, and 4.5°C by the 2080s, due to GHGs. Summer temperatures will increase by 2.2°C in the 2050s and 3.2°C in the 2080s. Extreme temperatures and heat spells have already become common over Northern India,. According to Lal *et al.,* 2001, an annual mean area-averaged surface warming over the Indian subcontinent range between 3.5 and 5.5°C over the region by 2080s. These projections showed more warming in winter season over summer monsoon. The spatial distribution of surface worming suggests a mean annual rise in surface temperatures in north India by 3°C or more by 2050. The study also suggest that during winter the surface mean air temperature could rice by 3°C in northern and central parts while it would rise by 2°C in southern parts by 2050. Over the Indian region the warmin will be restricted to 1.4± 0.3°C in the 2020s, 2.5±0.4°C in the 2050s and 3.8±0.5°C in the 2080s.

Effects on monsoon:

India is heavily dependent on the monsoon - to meet its agricultural and water needs, and also for protecting and propagating its rich biodiversity. The scientists warn that India will experience a decline in summer rainfall by the 2050s.Since summer rainfall accounts for almost 70 per cent of the total annual rainfall over India and is crucial for Indian agriculture, this could have a devastating effect on the Indian economy, and on food security. In case of rainfall, a marginal increase of 7-10 per cent in annual rainfall is projected over the sub-continent by the year 2080. However, the study suggests a fall in rainfall by 5 to 25 per cent in winter while it would be 10 to 15 per cent increase in summer monsoon rainfall over the country. It was also reported that the date of onset of summer monsoon over India could become more variable in future. (Lal *et al*., 2001).

Effects on water resources:

Relatively small climatic changes can cause large water resource problems, particularly in arid and semi-arid regions such as northwest India. This will have an impact on agriculture, drinking water, and on generation of hydroelectric power, resulting in limited water supply and land degradation. Rising temperatures will also contribute to the raising of the snowline, reducing the capacity of this natural reservoir, and increasing the risk of flash floods during the wet season. Increase in temperatures can lead to increased eutrophication in wetlands and fresh water supplies. According to 4th Assessment Report of IPCC, 2007, the 120 million to 1.2 billion people in Asia will experience increased water stress by 2020 and 185 to 981 million by 2050. The per capita water availability in India will drop from around 1900 cubic meter currently to 1000 cubic metres by 2025.

Effects on agricultural production:

– Higher temperature reduces 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°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°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°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 declines by 5 per cent when temperature during March increases above normal by 1°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°C and rainfall by 2 mm at a CO_2 concentration of 460 ppm) in southern India.

– Studies conducted by IARI, New Delhi reported that a loss of 4 to 5 million tones in the overall wheat production with every 1°C increase in temperature through out the growing period of the crop.

– In Rajasthan, a 2°C rise in temperature was estimated to reduce production of pearl millet by 10-15 per cent.

–The loss in farm-level net revenue will range between 9 and 25 per cent for a temperature rise of 2-35°C. (Kumar and Parikh, 1998).

Effects on pests (diseases and insects):

Climate change has the potential to modify host physiology and resistance and to alter the stages and rates of development of the pathogen. The most likely impacts would shift in the geographical distribution of the host and pathogen, change in the physiology of host-pathogen interactions and change in crop losses. New disease complexes may arise and some diseases may cease to be economically important if warming causes a pole ward shift of agroclimatic zones and host plant migrate into

new regions. Pathogen would be following the migrating hosts and may infect vegetation of natural plant communities not previously exposed to often more aggressive strains from agricultural crops. Rise in surface temperature will create more conducive conditions for pest infection, which is already a major constraint in achieving higher crop production in India, and hence loss of crop. Pathogens in which the primary source of infection is infected seed or the spores in air currents like *Ustilago tritici* (loose smut of wheat), *Puccinia* spp. (wheat rusts) etc., the warming of winters will allow an earlier migration resulting in earlier infection and longer epidemics. Population of cereal aphids has been predicted to increase in the coastal than in the continental regions.

Projected climate change scenarios for India:

According to Lal *et al* (2001), an annual mean area-averaged surface warming over the Indian subcontinent to range between 3.5 and 5.5^{O}C over the region by 2080s. These projections showed more warming in winter season over summer monsoon. The spatial distribution of surface warming suggests a mean annual rise in surface temperatures in north India by 3^{O}C or more by 2050. The study also suggest that during winter the surface mean air temperature could rice by 3^{O}C in northern and central parts while it would rise by 2^{O}C in southern parts by 2050. In case of rainfall, a marginal increase of 7-10 per cent in annual rainfall is projected over the sub-continent by the year 2080. However, the study suggests a fall in rainfall by 5 to 25 per cent in winter while it would be 10 to 15 per cent increase in summer monsoon rainfall over the country (Table 2). It was also reported that the date of onset of summer monsoon over India could become more variable in future. Though some of the projected changes in climate will have both beneficial and adverse effects on the environmental and socio-economic system, the larger changes will have more adverse effects.

Table 2 : Climate change projections for India

Year	Season	Temperature change (^{o}C)		Rainfall change (%)	
		Lowest	Highest	Lowest	Highest
2020s	Annual	1.00	1.41	2.16	5.97
	Rabi	1.08	1.54	-1.95	4.36
	Kharif	0.87	1.17	1.18	5.10
2050s	Annual	2.23	2.87	5.36	9.34
	Rabi	2.54	3.18	-9.22	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Annual	3.53	5.55	7.48	9.90
	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

(Source: Lal *et al.,* 2001)

The expected changes in climate for India indicated that increase in temperature is likely to be less in *Kharif* than in *Rabi* season and the *Rabi* rainfall is largely uncertain whereas *Kharif* rainfall is likely to increase by 10 per cent. Such global climate changes will affect agriculture considerably through its direct and indirect affect on crops, livestock, pest and diseases and soils, thereby threatening the food security, an important problem for most of the developing countries.

The impact of climate change on different crop management levels *viz.,* fertilizer, water management improving rainwater management through watershed development, increasing water availability and water use efficiency needs to be looked into it. All the soil processes with respect to changes in precipitation pattern and increased air and soil temperatures can influence water content, runoff and erosion.

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