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CLIMATE CHANGE: CAUSES, CONTRIBUTORS AND ITS IMPACT ON CROP PRODUCTION

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Abstract- Climate change is an important issue affecting the agriculture, forestry, industry etc. The assessment of impact of climate change on crop production is bit difficult, because of the complex process going on in the plants system, which responds differently to change in individual factor of climate. The crops phenology is expected to be advanced due to rise in temperature, and will shorten the period of the crop growth. On the other hand increase in the concentration of the carbon dioxide may increase the crop yield due to fertilization effect of CO_2. With the rise in temperature, insect pest population and occurrence of plant disease may be another threat to the crop productivity.Improved soil/crop management practices withpotential of soil organic carbon sequestration including conservation tillage, judicious use offertilizers, manures and diverse crop rotations may be followed to mitigate the effects of climate change on crop productivity.

Keywords: Climate change, global warming, crop production, Green house gases.

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Introduction

Climate change can be defined as a statistically significant variation in the mean state of the climate or in its variability persisting for alonger period (typically decades or longer). According to Intergovernmental Panel on Climate Change (IPCC), climate change is defined as “Any change in climate over time, whether due to natural variability or as a result of human activity”. United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as “A change of climate, which is attributed directly or indirectly to human activities that alter composition of the global atmosphere, which are in addition to natural climate variability observed over comparable time period”. Changes in climate are mainly a due to increase in theproduction/emission of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone, water vapors, and chlorofluorocarbons (CFCs), etc. which resulted in increase in atmospheric temperature, moreerratic rainfall pattern, melting of glaciers, rise in sea level etc. the concentrations of CO_2, CH_4, N_2O and CFCs in the atmospheric between 1000-1750 AD were 280 ppm, 700 ppb, 270 ppb and 0 ppt, respectively, but these values increased to 379 ppm, 1774 ppb, 319 ppb and 5.03 ppt, respectively [1] in 2005 and the concentration of the gases in the year 2014 further increased to 392.6 ppm (CO_2), 324 ppb (N_2O) and 1803ppb (CH_3) [2] [Table-1].Theincrease in the concentration of green house gases have resulted in warming of the atmosphere by 0.74 ^{0}C during 1906-2005 [3]. The rate of warming has been much higher in the recent decades and the minimum temperature at night has been increasing at twice the rate of day time maximum temperature.

Climate change affects agriculture and food production directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of farm incomes worldwide [4]. The production of crops such as wheat, rice, maize, soybeans, barley and sorghum accounts for over 40% of the global cropland area, 55% of non-meat calories and over 70% of animal feed. [5] .Rain-fed crops including pulses that account for nearly 60% of the cropland area will have drastic impacts of climate change. A 3-4°C rise in temperature could result in crop yields reduction of 15-35% in Africa and west Asia and 25–35% in the Middle East.[6].In the summer of 2003, Europe experienced extreme climate event with temperatures rise of up to 6°C above long term means and precipitation deficits up to 300 mm. The crop yield reduction of 36% was observed in Italy for corn grown in the Po valley where extremely high temperatures prevailed [7].

In Asian rice producing countries, rice yields will decrease dramatically due to higher nighttime temperatures and the rice yields are expected to decline by 10% for each 1°C increase in nighttime temperatures [8].While, the yield of wheat is expected to decline by 5–8% [9] and by 10% [10] per 1°C rise in mean seasonal temperature. Extreme climatic events (especially hotter, drier conditions in semi-arid regions) are likely to reduce yields of maize, wheat, rice and other primary food crops. In Latin America, rain-fed maize production will bear more yield losses as compared to irrigated production; some models predict losses up to 60% for Mexico, where around 2 million smallholder farmers depend on rain-fed maize cultivation [11].

Causes and contributors to climate change

Apart from natural activities, anthropogenic activities cause emission of greenhouse gases, particularly CO_2, CH_4, CFCs and N_2O. The largest increase in GHG emissions has come from energy generation, transport and industry, while residential and commercial buildings, forestry and agriculture sectors have been growing at a lower rate. Atmospheric concentrations of CO2 have been risingsteadily, from approximately 315 ppm in 1959 to approximately 385 ppm in 2008 [12] and 392.6 ppm in 2014 [2] Current projections showed that the concentrations of carbon dioxide will continue to rise to as much as 500–1000 ppm by the end of this century[1]. The GHGs trap heat radiated from the earth and increase global mean temperature. The Intergovernmental Panel on Climate Change (IPCC) reported that mean global temperature may increase by 0.3°C per decade [13] with an uncertainty of 0.2–0.5% [14] and would reach to approximately 1°C and 3°C above the present value by years 2025 and 2100, respectively, which would lead to global warming. This increase in temperature may lead to altered geographical distribution and growing season of agricultural crops by affecting the threshold temperature for the crop growth, development and maturity [15]. High ambient temperature has been identified as a serious threat to crop production worldwide [16,17].

Agricultural land use is considered to be CO2 neutral because the CO2 emission is almost equal to the CO2 fixed through photosynthesis. However the other GHGs, viz. CH4 and N2O are important due to their role in biogeochemical carbon and nitrogen cycling, global warming potential (GWP) and the atmospheric chemistry. Agriculture sector emitted 371.7 million tonnes of CO2 eq. (enteric fermentation 212.09, manure management 2.44, rice cultivation 84.24, agricultural soil 64.7 and crop residue burring 8.21 million tonnes) during 2007 comprising 13.84 million tonnes eq. of CH4 (enteric fermentation 10.10, manure management 0.12, rice cultivation 3.37 and crop residue burning 0.25 million tonnes) and 0.23 million tonnes of N2O (Agricultural soil 0.22 and crop residue 0.01 million tonnes. Enteric fermentation constituted 61 per cent of the total CO2 eq. emission from this sector and 20 % of the emissions were from rice cultivation. Agricultural soils emitted 16-20 % of the total CO2 eq. emission from agriculture [18,19]. The remaining 3 per cent of the emissions are attributed to livestock manure management and burning of crop residues in field. Accordingly, changes in agricultural management practices that influence the factors regulating CH4 and N2O production and emission, may change the global atmospheric budgets of these gases [20].

Table-1 *Relative increase in GHGs influenced by anthropogenic activities*

Gases	Year				Atmospheric lifetime (years)	Anthropogenic sources
	1750	1991	2005	2014		
CO_2 (ppm)	280	353	379	392.6	Variable	Fossil fuels combustion, land use conversion, cement production
CH_4 (ppb)	715	1720	1774	1803	12.2	Fossil fuel, rice stubbles, waste dumps, livestock
N_2O (ppb)	270	310	319	324	120	Fertilizer, industrial processes combustion
CFC's (ppt)	0		5.03		102	Liquid coolants, foams

(Source: [2, 20, 21])

Indian Network for Climate Change Assessment (INCCA) Report [22] showed that the net GHGs emissions were 1727.7 million tons (Mt) of CO2-equivalent (eq.) from India in 2007 of which CO2 emissions were 1221.76 Mt; CH4 emissions were 20.56 Mt; and N2O emissions were 0.24 Mt; GHG emissions from energy, industry, agriculture, and waste sectors constituted 58, 22, 17 and 3% of the net CO2 eq. emissions respectively. Energy sector emitted 1100.06 Mt of CO2 eq. of which 719.31 Mt of CO2 eq. was emitted from electricity generation and 142.04 Mt of CO2 eq. from the transport sector. Industry sector emitted 412.55 Mt of CO2 eq. Land Use Land Use Change & Forestry (LULUCF) sector sequestered 177.03 Mt of CO2. India's per capita CO2 eq. emissions including LULUCF were 1.5 tons/capita in 2007. The main sectors contributing to this emission are energy, industry, agriculture and waste. With a total emission of 334 Mt CO2 equivalents, the major sources in the agricultural sector are enteric fermentation (63.4%), rice cultivation (20.9%), agricultural soils (13.0%), manure management (2.4%) and on-field burning of crop residues (2.0%). The crop production sector (rice cultivation, soil and field burning of crop residues), thus contributes 35.9% to the total emissions from agriculture.

Effect of climate change on crop phenology

Phenology is a susceptible biosphere indicator of climate change [23]. Plant phenological stages had occurred 2–3 days earlier in spring and delayed by 0.3–1.6 days in autumn per decade [24,25,26]. It was reported that the increase in temperature would affect the crop calendar in tropical regions. Global warming is expected to reduce the duration of the effective growing period due to sustained temperature rise, particularly in the areas with intensive cropping pattern[27],whereas short period of high temperature at critical developmental stages of crop can reduce crop yield [28]. High temperatures can change the annual timing of bud break, flowering, seed production and other phenophases [15,29]. The occurrence of high temperature could alter the number, size and orientation of the leaves and the depth of plant roots. The high daytime and nighttime temperatures reduces grain-filling development in maize, fruit trees and vineyards accelerated crop ripening and maturity by 10–20 days and resulted in increased water consumption in agriculture [30] .

Average advance of 1.1 – 1.3 days per decade in 78 agri-horticultural phonological events between 1951 and 2004 was observed that was also due to rise in temperature during the period [31]. Growing season shortened by 2.3 days per decadeas a result of increase in mean annual air temperature of 0.36°C per decade in Germany for the period 1961–1990[32] and was also validated with CERES-Rice model under Punjab conditions [33]. The results indicated a decline in crop duration, grains m-2, grain yield, maximum LAI, grains per ear, biomass and straw yield with each 0.5 °C increase in temperature over the normal during the crop season. Under the warm climatic scenarios, the reduced source size coupled with poor sink strength reduced number of effective tillers and shorter period of harvesting solar radiation (crop duration) which resulted in considerable decline in biologicals and grain yield of rice crop over the normal. The occurrence of high temperature adversely affects plants growth and causes severe cellular injury and that could lead to acatastrophic collapse of cellular organization due to starvation, inhibition of growth and production of toxic compounds, which may cause cell death [34]

Effect of climate change on pest population dynamics and emergence of new pests

Annual loss of US$85 billion due to pathogens and US$45 billion due to insect damage has been reported worldwide [35].Temperature is the most important factor affecting insect ecology, epidemiology and distribution; whereas plant pathogens are more responsive to humidity, rainfall and temperature [36].Climate change can affect pathogen and insect pest dynamics in multiple ways. Higher temperatures may lead to faster disease cycles in airborne pathogen and pest organisms[37].

The occurrence of higher temperature increases the rate of development in insects and pathogens with smaller time between subsequent generations. It has been estimated that insects may have one to five additional lifecycles per season with a 2°C rise in temperature [38]. The insect survival may further be amplified in warmer winters leading to rise in insect population in the subsequent growing season [39, 40]. The rise in temperature due toclimatic changes could affect crop insect pest populationsin multiple ways [41] like (a) expansion in area (b) increased over-wintering (c) changes in crop pest synchrony (d) increase in number of life cycles(e) extended development season (f)changes in growth rate (g) changes in within species interaction (h)higher risks of invasions by migrant pests and (i) introduction of alternative hosts and over-hosts.

Effect of climate change on disease development

Temperature, rainfall, humidity, radiation and dew are the important climatic factors that can affect the growth, development and spread of fungi and bacteria [42]. Air pollution, particularly ozone and UV-Bradiation [43], nutrient (especially nitrogen) availability [44] are other factors influencing plant diseases incidence. Higher microclimate relative humidity will promotes plant diseases such as rusts, powdery mildews, leaf spots and bacterial blights [43]

In the temperate climates of Japan, it was observed that elevated carbon dioxide increased the potential risks for infection from leaf blast and epidemics of sheath blight in rice [45].With the rise in temperature, wheat and oats will become more susceptible to rust diseases [36]. Increase in temperature along with changing vapour pressure deficits will alterrelative humidity in the crop canopy that will create favourable conditions for the insect– pest and disease development at a frequency and intensity higher than normal.

An example of such a scenario is the severe incidence of yellow rust on wheat variety PBW-343 in Punjab in February 2009 and exceptional infestation by brown plant hopper on rice varieties in Kharif 2008 in Punjab and Haryana. An adaptation by a strain of yellow rust was never noticed in past at such temperature situations. Such consequences are very difficult to predictable and may occur with many other pathogens and pests [46]

Effect of climate change on crop productivity

The assessment of impact of climate change on crop productivity is difficult due to differential response of different plants processes to changes in temperature, CO2 concentration, and other climatic factors. Crop growth and yield is affected by a number of biotic and abiotic stresses. The probability of occurrence of extreme climatic events such as floods, drought, extreme temperatures and aerosol has increased in the past few decades. Global analysis of crop yields from 1981 to 2002 showed a negative response of wheat, maize and barley yields to rising temperature, costing an approximate loss of about $5 billion/year [47]. The loss may exceed an approximately amount of $56 billion due to loss of 280 million tonnes of potential cereal production[48].As per studies, Latin America and Africa may experience a 10 percent reduction in maize productivity by 2055 that will cost $2 billion/year. A reduction of 30 per cent or more in agricultural output has been projected in Africa and Indiaduerise in temperature and changes in rainfall patterns, that may result in 10 million tons/year additional losses of maize grain costing about $5 billion [49, 50].Temperature, solar radiation and water directly affects the physiological processes involved in grain development and indirectly affects the grain yield by influencing the incidence of disease of insect and diseases [51]. They found that the rice grain yield was correlated positively with average solar radiation and negatively with average daily mean temperature during reproductive stage. Relatively low temperature and high solar radiation during reproductive stage had positive effect on number of spikelet's and hence increased the grain yield. Solar radiation had positively influenced grain filling during the ripening period.

The historic data analysis of 20 climate change models [52] showed that climate change would adversely affect the developing regions of southern Africa, South Asia, Central America and Brazil. The average temperatures would increase by 1°C in most areas of the world by 2030. They further concluded that maize requires a huge amount of water and nutrition so it will not be the best crop for African regions that will experience severedrought. Drought-resistant sorghum might be a best alternative. These strategies would not be enough for such regions and they will require more expensive remedies, such as introduction of new crop varieties and expansion in irrigation system. The simulation results further showed that the fertilizing effect of CO2 would probably counteract the negative impact of warming on low latitudes for few decades and warming would negatively affect food production in developing countries as compared to developed ones, because many richer countries are in colder regions, which might benefit from warming and are probably more adaptable to changing conditions. While, it was reported that developed countries are actually more susceptible to the unpredictability of weather, while poorer nations, on the other hand, have a low production rate and will be more affected by other factors, such as the availability of fertilizer [52].In a simulation study using CERES-rice modelit was reported that with 100 ppm increase in the atmospheric CO2, the grain yield of rice increased up to 6% under optimum supply of nutrients and water [53]. The long duration variety showed better adaptability to climate change than the medium-duration varieties under optimal input management conditions.

The yield of rice and wheat increased by 15 and 28per cent, respectively for a doubling in CO2 concentration in NW India [54].In another study the it was reported that the grain yield of rice would increase by 1.5, 6.6 and 8.7% with enhanced CO2 concentrations of 400, 500 and 600 ppm, respectively as compared to base level of 330 ppm CO2 [55, 56].An increase in yield of wheat to the extent of 29-37per cent and 16-28per centwas observed for different varieties, under rainfed and irrigated conditions, respectively, for a temperature rise coupled with elevated CO2 (Tmax + 1.0°C, Tmin + 1.5°C and 460 ppm CO2) compared with the current climate [57].

Plant grow this also stimulated by increase in CO2 concentrations, because photosynthesis is stimulated by elevated CO2, at least in C3 plants, secondly in almost all species, stomatal closure is induced in response to the increased availability of CO2. Lower stomatal conductance also resulted in reduced evapotranspiration, which in turn can result in comparably higher soil moisture at any given plant biomass, or to the maintenance of higher plant biomass at any given level of soil H2O [58 , 59 ,60]. The increase in CO2 concentration in the atmosphere could enhance plant growth by increasing the photosynthetic rate resulting in more leaf expansion and a large canopy. Photosynthesis is the net accumulation of carbohydrates formed by uptake of CO2. From an experiment it was concluded that 3°C rise in temperature will nullify the fertilization effects of elevated CO2 [57].

In northwest India, it was reported that the yield showed differential response to increase in seasonal temperature [61]. The extent of reduction in wheat yield due to temperature rise was the highest in Haryana(4.29q/ ha/°C), followed by Rajasthan (2.49q/ha/°C), Punjab (0.62q/ha/°C) and Uttar Pradesh (0.56q/ha/°C). Almost similar trend was observed in barley crop. The extent of decrease in chickpea yield was maximum (3.01 q/ha/°C) in Haryana, followed by 1.81, 1.27 and 0.53q/ha/°C in Punjab, Rajasthan and Uttar Pradesh, respectively. The yield of rapeseed mustard was reduced by 2.01q/ha/°C in Haryana, followed by 0.98 and 0.92 q/ha/°C, respectively, in Uttar Pradesh and Rajasthan. By pooling of the datasets for all the locations, reductions in yield per degree rise in temperature were 4.26, 2.77, 0.32 and 1.32 q/ha/°C for wheat, barley, chick pea and mustard, respectively.

While evaluating the effect of seasonal temperature change on yield of early-, medium and late-duration varieties of maize, a decreasing trend in yield was observed with temperature rise [62]. The magnitude of reduction in yield varied with the duration of maize varieties. Decrease in yield was maximum (4.6 q/ha/°C) in the late-duration varieties, followed by the medium-duration varieties (4.3 q/ha/°C) and the early duration varieties (3.2 q/ha/°C).In India, it was observed that the adverse effects of 1-2oC rise in temperature could be nullified with 5-10 per cent increase in precipitation [63]. The productivity increase of 20-30 per cent may be possible on about 70 per cent area under rice and wheat. In northern India, warming could offset some losses in yield by early pod set in winter grain legumes like chickpea and lentil. In simulation studies to find the impact of climate change on wheat productivity for several locations in India, the results indicated that, in northern India, a 1°C increase in the mean temperature had no significant effect on potential yields, though an increase of 2°C reduced potential grain even with the beneficial effects of CO_2 on crop yield [65]. Yield reductions were due to a shortening of the growing season, resulting from an increase in temperature. A 2°C increase in temperature resulted in a 15-17% decrease in grain yield of rice and wheat but, beyond that, the decrease was very high in wheat [66]. The grain filling of wheat is seriously impaired by heat stress due to reductions in leaf and ear photosynthesis [67].In a study on the impact of temperature rise in March 2004 on the productivity of wheat, it was shown that the temperature increase above normal ranged from 1-12°C in parts of northern India, resulting in a wheat production loss of 4.6 million tonnes due to increased incidences of insect-pests, diseases and advanced maturity of wheat by 10-20 days further reduced grain weight [68].

Management intervention to mitigate the adverse the impacts of climate change

Adaptive options to deal with the impact of climate change are:

- Use of heat, salinity and drought resistance/tolerant crop varieties
- Proper water management (Tensiometer, SRI, DSR, Laser-aided land leveling, Raised-bed planting)
- Reducing the emission of green house gases from agricultural as well as industrial sectors (Reducing farm operation, Better management of fertilizers)
- Efficient utilization of available resources using resource conservation technologies (Conservation tilling/zero tilling/ Zero tillage, Crop residue retention, IPM)
- Improving the nutrient and energy use efficiency (use of SSNM, LCC and Optical sensors etc)

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