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RESEARCH ARTICLE

SOURCES OF GREENHOUSE GASES EMISSION AND THEIR IMPACT ON CROP PRODUCTION: MITIGATION STRATEGIES FOR CHANGED CLIMATIC SCENARIO

***Avtar Singh, Harmeet Singh, J. S. Kang and Jasvinder Singh**

Department of Agronomy, Punjab Agricultural University, Ludhiana-141 004

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ABSTRACT

Climatic variability and changes in the last decade is the great threat to the sustainability in food grain production in India. In spite of technological advances, weather and climate are playing vital role in Indian agriculture. Change in climate is mainly a result of increased production of CO_2, methane (CH_4), Nitrous oxide (N_2O), ozone, water vapors, Chlorofluorocarbons (CFCs), which resulted in increase in atmospheric temperature, disturbance in quantity and distribution of rainfall, melting of glaciers, rise in sea level etc. The change in climate of the world has mainly brought out by rapid industrialization, deforestation, increased agricultural operations, combustion of fossil fuels, increased number of vehicles, etc. and the driving force behind these factors is ever increasing human population requiring more food and space to live. It is resulted in global warming. This is happened due to the increase in concentration of GHGs in the atmosphere, and leads to a phenomenon widely known as 'Greenhouse Effect'. Elevated temperature, CO_2, rainfall and drought, flooding and storm affect the agriculture.

INTRODUCTION

Indian, self sufficiency and sustainability in food grain production is under threat due to the climatic variability and changes that had occurred in the last decade. In spite of technological advances such as improved crop varieties, production and protection measures and irrigation facilities, weather and climate are playing key role in Indian agriculture. Several climatic models predict that global warming in future may reduce over large area of semi-arid grasslands in North America and Asia. It is predicted that there will be a 17 % increase in desert land at global level due to climate change expected from a doubled concentration of atmospheric CO_2 (Rao and Ramakrishna 2008). It is interesting to mention here the scientists, common man and politicians all over the world has started thinking that global warming will have a major impact on agro-ecosystems that is why United Nations Environment Program (UNEP) along with World Meteorological Organization (WMO) established the Inter-Governmental Panel on Climate Change (IPCC) in 1988 to periodically assess the state of global environment and to advice various UN agencies on climate change.

MATERIALS AND METHODS

In this article discussed the causes of climate and contribution of different sources, GHGs emission from various crop and animal food products, effect climate changes on ecosystem, temperature, rainfall, projected impact climate change on Indian agriculture, effect of elevated carbon dioxide, temperature and rainfall on agriculture, interactive effect changing climate on crop production effect of elevated temperature and rainfall on nutrient cycling, water requirement of plants, fertilizer requirement, effect of climate change on rice-wheat productivity, strategies to deal with changed climatic scenario and researchable issues by consulting the different contribution of the scientists who are working on climate change.

RESULTS AND DISCUSSION

Climate change

Climate change can be defined as a statically significant variation in either the mean state of the climate or in its variability persisting for an extended period (typically decades or longer). Intergovernmental Panel on Climate Change (IPCC) defined climate change 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) also 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". The effects of climate change have reached such an extent that irreversible changes in the functioning of the planet are feared. Some of the main effects

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***Corresponding author: Avtar Singh**
Department of Agronomy, Punjab Agricultural University, Ludhiana-141 004

of climate change with specific reference to agriculture and food production especially during the last decade are:

- increased occurrence of storms and floods
- increased incidence and severity of droughts and forest fires
- increased frequency of diseases and insect pest attack and vanishing habitats of plants and animals.

Carbon dioxide (CO_2) is the major anthropogenic green house gases (GHGs). Its annual emissions have been increased between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (94.4 to 170.8 ton), and represented 77 % of total anthropogenic GHGs emissions in 2004. The rate of growth of CO_2-equivlent emissions was much higher during the last decade of 1995-2004 [0.92 Gt (4.14 ton) CO_2- equivalent per year] than last two and a half decade of 1970-1994 [043 Gt (1.93 ton) CO_2-equivlent per year]. The largest increase in GHG emissions between 1970 and 2004 has come from energy supply, transport and industry, while residential and commercial buildings, forestry (including deforestation) and agriculture sectors have been growing at a lower rate. Change in climate is mainly a result of increased production of CO_2, methane (CH_4), Nitrous oxide (N_2O), ozone, water vapors, Chlorofluorocarbons (CFCs), which resulted in increase in atmospheric temperature, disturbance in quantity and distribution of rainfall, melting of glaciers, rise in sea level etc. the concentrations of CO_2, CH_4, N_2O and CFCs between 1000-1750 AD were 280 ppm, 700 ppb, 270 ppb and 0 ppt, respectively (Table 1), but in 2005, these values increased to 379 ppm, 1774 ppb, 319 ppb and 5.03 ppt, respectively (Kaur and Hundal 2008). These increases in concentration of green house gases have resulted in warming of the atmosphere by 0.74 ^{0}C during 1906-2005. Eleven out of the twelve years (1995-2006) rank amongst the twelve warmest years since 1850. 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 (Kaur and Hundal 2008).

Causes of climate change and major contributors

The change in climate of the world has mainly brought out by rapid industrialization, deforestation, increased agricultural operations, combustion of fossil fuels, increased number of vehicles, etc. and the driving force behind these factors is ever increasing human population requiring more food and space to live. It is resulted in global warming. This is happened due to the increase in concentration of GHGs in the atmosphere, and leads to a phenomenon widely known as ‘Greenhouse Effect’.

Amongst various sources of GHGs, agriculture is considered a major contributor primarily through the emission of MH_4 and N_2O. As per Indian Network for Climate Change Assessment (INCCA) Report (2010), the net GHGs emissions were 1727.7 million tons (Mt) of CO_2-equivalent (eq.) from India in 2007 of which CO_2 emissions were 1221.76 Mt; CH_4 emissions were 20.56 Mt; and N_2O emissions were 0.24 Mt; GHG emissions from Energy, Industry, Agriculture, and Waste sectors constituted 58, 22, 17 and 3% of the net CO_2 eq. emissions respectively. Energy sector emitted 1100.06 Mt of CO_2 eq. of which 719.31 Mt of CO_2 eq. was emitted from electricity generation and 142.04 Mt of CO2 eq. from the transport sector. Industry sector emitted 412.55 Mt of CO_2 eq. LULUCF sector was a net sink. It sequestered 177.03 Mt of CO_2.India’s per capita CO_2 eq. emissions including Land Use Land Use Change & Forestry (LULUCF) were 1.5 tons/capita in 2007. The major cause to climate change has been ascribed to the increased levels of GHGs like CO_2, MH_4, N_2O, and CFCs. The main sectors contributing to this emission are energy, industry, agriculture and waste. With a total emission of 334 Mt CO_2-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.

Beyond their natural levels due to the uncontrolled human activities such as burning of fossil fuels, increased use of refrigerants, and enhanced agricultural activities. These GHGs are nearly transparent to the visible and near infra-red wavelengths of sunlight but they absorb and re-emit downward a large fraction of the longer infra-red radiation emitted by earth. As a result of this heat trapping, the atmosphere radiates large amounts of long wavelength energy downward to the earth’s surface and long wavelength radiant energy received on earth is increased. Agriculture sector emitted 371.7 Mt of CO_2 eq. (Enteric fermentation 212.09, manure management 2.44, rice cultivation 84.24, agricultural soil 64.7 and crop residue burring 8.21 Mt) during 2007 comprising 13.84 Mt eq. of CH_4 (Enteric fermentation 10.10, manure management 0.12, rice cultivation 3.37 and crop residue burring 0.25 Mt) and 0.23 Mt of N_2O (Agricultural soil 0.22 and crop residue 0.01 Mt. Enteric fermentation constituted 61 % of the total CO_2 eq. emission from this sector and 20 % of the emissions were from rice cultivation. Agricultural soils emitted 16 % of the total CO_2 eq. emission from agriculture (Bhatia *et al.*, 2010). The remaining 3 % of the emissions are attributed to livestock manure management and burning of crop residues in field.

Table 1. Relative increase in GHGs influenced by anthropogenic activities

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

Source: Kaur and Hundal (2008)

Carbon Dioxide

It is a colorless, odorless non-flammable gas. CO_2 is the most prominent greenhouse gas in earth's atmosphere. Every year humans add over 30 billion tons of CO_2 in the atmosphere by these processes. The rapid increase in atmospheric concentrations of carbon dioxide over years is linked with combustion of fossil fuels, conversion of forested land to agricultural use and changes occurring in various carbon pools and fluxes (Table 1). There has been growing concern in recent years that these high levels of greenhouse gases may not only lead to changes in the earth's climate system, but may also alter ecological balances through effects on vegetation. Terrestrial ecosystems act as both source and sink and large uncertainty exists in understanding the current carbon status and its spatial and temporal variability. CO_2 is increasing at the rate of 1.5 ppm per year. Half of the green house effect is expected due to CO_2.

Methane

Methane is a colourless, odourless, flammable gas. It is formed when plants decay and where there is very little air. It is often called *swamp gas* because it is abundant around water and swamps. Methane is the second most important greenhouse gas after carbon dioxide and contributes about15% to the global warming. Rice cultivation has been accredited as one of the major source of anthropogenic methane (Manjunath *et al.,* 2009). With the intensification of rice cultivation to meet the growing global food demand, CH_4 emission from this important ecosystem is anticipated to increase. It was observed that all India monthly average atmospheric concentration of methane ranges from 1693 to 1785 ppb. A systematic seasonal pattern was observed in methane concentration, which was mostly influenced by rice growth characteristics. It was found that January to June is associated with relatively lower concentration of methane (1699-1708 ppb) in India, which characteristically increases from July to September (1747-1785 ppb) with further gradual decline from October to December (1768-1704 ppb). The satellite based spatial variability of methane is in accordance with field based methane emission measurements. The spatial distribution of methane over Indian region is associated with agricultural practices particularly rice cultivation. It was observed that Indo-Gangetic plain including North-eastern region, parts of Chhattisgarh, Orissa and Andhra Pradesh showed higher methane concentration (> 1730 ppb) as compared to hilly regions of Jammu and Kashmir (< 1710 ppb). Pathak *et al.* (2010) reported that the highest seasonal methane emission (average 875 kg/ha) from rice field was observed at Ludhiana, Punjab followed by North 24 Paraganas, west Bengal (average 305 kg/ha), Barrack, West Bengal (average 222 kg/ha), Jorhat, Assam (average 175 kg/ha), Bhubaneswar, Orissa (average 163 kg/ha), Nadia, West Bengal (158 kg/ha), Maruteru, Andhra Pradesh (average 150 kg/ha), Madras, Tamil Nadu (average 149 kg/ha) and other places below 120 kg/ha. The lowest was observed at Allahabad, Uttar Pradesh average 5 kg/ha.

Source

- Rice fields are one of the most important sources of atmospheric CH_4 with a global emission of CH_4 estimated between 60 and 150 Tg/year. Flooding of rice fields stops the influx of atmospheric oxygen into the soil and decomposition of organic matter becomes anaerobic.
- Methane is also found in the digestive track of ruminants and in the guts of various insects of which termites are the most important. Methane has two times greater capacity for global warming than that of CO_2. About 20 per cent of the global warming is caused by methane.

The total output of methane into the atmosphere from all sources in the world is estimated to be 535 Tg/year. India's contribution to global methane emission from all sources is 18.5 Tg/year. Agriculture largely rice and ruminant animals are the major (68%) is the major contributor to its emission.

Nitrous Oxide

Nitrous oxide (N_2O) is another colourless greenhouse gas however, it has a sweet odour. Nitrogen oxides play a central role in tropospheric chemistry. An improved knowledge of the global tropospheric distribution of NOx ($NO+NO_2$) is important for climate change studies. NOx and volatile organic compounds are emitted in large quantities due to human activities such as vehicles and industry (Table 2). The knowledge of the ozone distribution and its budgets is strongly limited by a severe lack of observations of NO and NO_2 in the troposphere. The technique used to retrieve total slant columns of atmospheric trace species from Satellite measurements is the Differential Optical Absorption Spectroscopy (DOAS). The DOAS technique allows the determination of concentrations of atmospheric species, which leave their absorption fingerprints in the spectra. Spatial distribution of tropospheric NO_2 concentration was analyzed over India. It was observed that high concentration of NO_2 distribution is associated with coal-mine and thermal power locations as well as major metropolitan cities of India.

Source

- This gas is released naturally from oceans and by bacteria in soils
- Through nitrogen based fertilizers
- Disposing of human and animal waste in sewage treatment plants
- Automobile exhaust
- N_2O gas has risen by more than 15% since 1750.
- Nitrogen based fertilizer use has doubled in the past 15 years.
- Oxides of nitrogen (gaseous form) have 10-1000 time greater effect on global warming than that of CO_2.

Chlorofluorocarbons (CFC's)

Fluorocarbon is a general term for any group of synthetic organic compounds that contain fluorine and carbon. The major source of CFCs is liquid coolants and foams (Table 1). CFC's are emitted into the atmosphere; they break down molecules in the Earth's ozone layer. CFC's have 10,000 times greater potential for global warming than that of CO_2. CFC's are used for refrigeration, aerosol propellant and for insulation. These are responsible for 15 % of the green house effect. The substitutes for CFC's are hydro fluorocarbons (HFC's). CFC's do not breakdown the ozone molecule, but they do trap heat in the atmosphere, making it a greenhouse gas, aiding in global warming.

Emission of GHG from various food products from crop and animal

Basically four stages of life cycle of food products i.e., production, processing, transportation and preparation are contributed in the emission of GHGs. Food products from animal determined the CH_4 emission, while food products from crop determined the emission of CH_4 (from rice cultivation) and N_2O (from all crops). Emission of CO_2 occurred during farm operations, production of farm inputs, transport, processing and preparation of food. Production of food products varied considerably in GHG emission (Table 2). For example, emission of GHG from production of ordinary rice was about 10.2 and 43.3 times higher than production of wheat and vegetables, respectively. Higher emission in rice was because of CH_4 emission under anaerobic soil condition, whereas, wheat, vegetables and other crops are grown in aerobic soil conditions and there is no CH_4 emission. Potato and other root vegetables have high productivity, resulting in low emission of GHG per unit food product. Production of food (meat and milk) from animal emitted larger amount of GHG compared to food from crops because of emission of methane by ruminants. The nature of GHG also varied for different food items. The food products from animal such as mutton, poultry meat, dairy products and fish dominated the CH_4 emission. On the other hand, the food products from crop contributed to N_2O emission except rice, which contributed to CH_4 as well as N_2O emission. Application of synthetic nitrogen fertilizers in agriculture was responsible for a major part of the N_2O emission. The GWP of food items was larger on dry weight basis than that with fresh weight basis However, as the foods are generally consumed fresh, the results lower GWP.

Table 2. Emission of greenhouse gases due to production of various food products from crop and animal

Crop/animal product	GHG emission(g/kg)			
	CH_4	N_2O	CO_2	GWP (CO_2 eq.)
Wheat	0.0	0.3	45.0	119.5
Rice	43.0	0.2	75.0	1221.3
Pulse	0.0	0.8	83.3	306.8
Cauliflower	0.0	0.1	13.3	28.2
Brinjal	0.0	0.1	12.5	31.1
Oilseed	0.0	1.3	50.0	422.5
Mutton	482.5	0.0	0.0	12062.7
Egg	0.0	2.0	1.0	588.4
Milk	29.2	0.0	0.0	729.2
Fish	25.0	0.3	18.8	718.3
Apple	0.0	1.0	41.7	331.4
Banana	0.0	0.2	10.0	71.6
Spice	0.0	2.5	100.0	845.0

Effect of climate change on ecosystem

Plant and animal species

The rapid pace of changes may be too quick for many organisms to adjust to changing habitats**.** About 80% of the existing forests are undergoing a change in the type of vegetation. Many species of plants and animals might not be able to cope with climate change and could, therefore, face “Extinction”.

Sea Level

Sea levels have risen between 4-10 inches since 1990. By 2100, there will be 2 foot rise in the sea level and it will continue to rise 2-3 feet per century, for 1000 years. It increases the salinity of freshwater throughout the world and cause coastal lands to be washed under the ocean. Warmer water and increased humidity will encourage tropical cyclones. Changing wave patterns could produce more tidal waves and strong beach erosion. Increased water vapour in the atmosphere, glaciers and polar ice caps appear to be melting, floods and droughts are becoming more severe. About 50 million acres of Asian region are already subjected to seasonal floods.

Observed changes in temperature

Change in atmospheric temperature has been reported by many workers. (Rao and Ramakrishna 2008) observed that an increase in air temperature over last 100 years (1850-1899 to 2001-2005) of 0.76°C in India. Sinha *et al*. (1998) found that in many parts of Northern India, there is an increase in minimum temperature by about 1°C in *rabi* season. Hingane *et al*. (1985) worked on long term trends of surface temperature in India from a period of 1900-1982 from 73 weather stations distributed over the country and found warming trend of 0.04°C/decade. Indian mean annual temperature has shown significant warming trend of 0.05 °C per decade during 1901-2003, the recent period 1971-2003 has a relatively accelerated warming rate of 0.22 °C per decade. Analysis of meteorological data of Punjab conducted by Kaur and Hundal (2008) revealed that the maximum temperature has decreased from normal at Ballowal Saunkri and at Bathinda, however, for other locations no trend could be established. The *kharif* maximum temperature decreased at a rate of 0.04 °C per year at Ballowal Saunkri and at Bathinda. The annual and seasonal minimum temperature has increased at the rate of 0.07°C/year over past three decades at Ludhiana. At Patiala the annual and *kharif* minimum temperature has increased at the rate of 0.02 °C per year and at Bathinda the annual, *kharif* and *rabi* minimum temperatures has increased at the rate of 0.03, 0.02 and 0.05°C per year, respectively. However no trend of change in minimum temperature was observed at Ballowal Saunkri and Amritsar.

Observed changes in rainfall

Rupa Kumar *et al*. (2002) observed that summer monsoon rainfall during 1901-2000 has shown significant decreasing trends in the sub-divisions of NE India, viz. Nagaland, Mizoram, Manipur and Tripura (-12.5mm/decade), Orissa (-11.0 mm/decade) and East Madhya Pradesh (-14.0 mm/decade). Significant increasing rainfall trends in Konkan and Goa (27.9 mm/decade) and coastal Karnataka (28.4 mm/decade) along the west-cost and in Haryana, Chandigarh and Delhi (13.6 mm/decade) and Punjab (18.6 mm/decade) were noticed in North India. Similarly, the winter monsoon rainfall has shown significant increasing trend in the sub-divisions of Marathwada (5.4 mm/decade), Telengana and North interior Karnataka (4.5 mm/decade), in central India and also in Gujarat (1.2 mm/decade). Hundal and Kaur (2002) observed an overall increase in rainfall over a period of 1970-1998 at different locations in Punjab, but during the period from 1999 to 2005 below normal rainfall was received at all the five locations (Ballowal Saumkri, Amritsar, Ludhiana, Patiala and Bathinda) during the year 1999, 2002, 2004 and 2005. In the year of 2000 below normal rainfall was recorded at Ludhiana and Patiala and during 2001 below normal rainfall was recorded at all the four locations except at Ludhiana. This resulted in arresting the increasing trend of rainfall at different locations in the state. Hence, no significant trend in increases/decreases of rainfall was noted at all locations except at Ballowal Saunkri where a significant decreasing trend was noticed.

Shift in monthly rainfall

Any shift in monthly rainfall has a direct bearing on agriculture as it influences various agricultural operations mainly the time of sowing and subsequent crop growth therefore necessitating shift in time of sowing and cropping patterns to match the modified rainfall regime. A study by Rajegowda *et al.* (2001) from Karnataka covering the period 1991-2000 indicated that shift in rainfall peaks by 2-3 weeks. Similarly, Sastri and Urkurkar (1996) observed trends of decreasing pattern in pre-monsoon rainfall in some parts of Chhattisgarh region in May and June proving detrimental to pre-sowing operations of rice.

Projected climate change in india

Projected change in seasonal temperature and rainfall is being presented in Table 3 as projected by Lal (2001).

Table 3. Climate change projected for India

Year	Season	Temperature change (°C)		Rainfall change (%)	
		Lowest	Highest	Lowest	Highest
2020	Annual	1.00	1.41	2.16	5.97
	Rabi	1.08	1.54	-1.95	4.36
	Kharif	0.87	1.17	1.81	5.10
2050	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
2080	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 (2001).

Projected impacts of climate change on Indian Agriculture

- Productivity of most cereals would decrease due to increase in temperature. Reports indicate a loss of 10-40 % in crop production by 2100 AD. Greater loss expected in *rabi.* Increased droughts and floods are likely to increase production variability
- The potential effect of climate change on agriculture is the shifts in the sowing time and length of growing seasons geographically

  Increased temperature would increase fertilizer requirement for the same production targets. However, increase in CO_2 concentration can lower pH, thereby, directly affecting both nutrient availability and microbial activity
- The effect of temperature rise will lead to an increase in soil biological activity as well as physical and chemical processes.
- The average atmospheric temperatures are expected to increase more near the poles than at the equator.
- Increased temperature resulting from global warming is likely to reduce the profit from cultivation and will compel farmers of lower latitudes to option for maize and sorghum, which are better adapted to higher temperature
- In mid-latitudes, crop models indicated that warming of less than a few °C and the associated increase in CO_2 concentrations will lead to positive responses and generally negative responses with greater warming

Effect of elevated Co_2 concentration on agriculture

Elevated CO_2 concentrations often stimulate plant growth, because photosynthesis is stimulated by elevated CO_2, at least in C_3 plants, secondly in almost all species, stomatal closure is induced in response to the increased availability of CO_2. Lower stomatal conductance can result 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 H_2O (Jackson *et al* 1998, Niklaus and Korner 2004, Owensby *et al.,* 1999).

Effect of elevated CO_2 on fertilization

The increase in CO_2 in the atmosphere could enhance plant growth by increasing the rate of photosynthesis leading to more leaf expansion and a large canopy. Photosynthesis is the net accumulation of carbohydrates formed by uptake of CO_2.

Effect of elevated CO_2 on C_3 and C_4 plants

C_3 plants respond more favorably to increasing CO_2 than C_4 plants because they tend to suppress rates of photorespiration. **P**roductivity of a crop community depends mainly on its photosynthetic capacity, which is highly dependent on climatic conditions. There are numerous reports, which suggest that environmental carbon dioxide concentration is increasing and as result temperature is also increasing. Both of these environmental variables play an important role in determining photosynthesis rates of the crop canopy. Carbon dioxide is a substrate for photosynthesis reactions. Atmospheric carbon dioxide reaches the chloroplasts, the site of photosynthesis reactions, by diffusion process through the pores on leaf surface called stomata. The temperature, at which a crop is exposed, influences activity of various enzymes including those responsible for photosynthesis. The difference in photosynthesis efficiency between C_3 and C_4 plants is due to photorespiration.

Causes for difference in photorespiration

Crop plants are broadly classified into two groups on the basis of the photosynthetic mechanism followed by them. Majority of cultivated species show first stable product of photosynthesis as a 3 carbon molecule called glyceric acid-3-phosphate and are called as C_3 plants. Whereas some crops like sugarcane, maize and sorghum have an additional mechanism of photosynthetic reaction in which the first stable product is a 4 carbon molecule. These plants are called as C_4 plants which are considered to be more efficient than C_3 plants. The advantage of C_4 mechanism over C_3 is most pronounced in the conditions of low carbon dioxide availability, high light intensity and high temperature. These conditions favour photorespiratory carbon loss leading to reduced net photosynthesis of C_3 plants. This photorespiration is negligible in C_4 plants due to leaf anatomy and enzymes involved in carboxylation. In C_3 plants, all the photosynthetic reactions take place in mesophyll cells which get atmospheric air having both carbon dioxide and oxygen in their natural proportion of approximately 20% O_2 and 0.03% CO_2. The enzyme Rubisco (ribulose-1, 5-bisphosphate carboxylase-oxygenase) has both properties of carboxylation (carbon fixation) as well as oxygenation responsible for photorespiration. Due to high availability of oxygen in mesophyll cells (where Rubisco is present), C_3 plants show considerable rate of photorespiration. Whereas in case of C_4 plants, carboxylation process of photosynthesis takes place in presence of enzyme phosphoenol pyruvate (PEP Case) in mesophyll cells in which both carbon dioxide and oxygen are available. This enzyme has very high affinity to CO_2 with no oxygenation property and hence, it can not utilize oxygen. The carbon dioxide fixed in mesophyll cells in form of 4 carbon acid is decarboxylated and pumped into bundle sheath cells where it is again carboxylated by the enzyme Rubisco. These bundle sheath cells are surrounded by mesophyll cells thereby limiting oxygen availability. Moreover, pumping of carbon dioxide from mesophyll cells increase carbon dioxide concentration in bundle sheath cells so much that all the reaction sites of Rubisco get sufficient carbon dioxide molecules to carry out carboxylation leaving negligible/no site for reaction with oxygen. The differences in leaf anatomy and enzyme involved in primary CO_2 fixation are responsible for differences in photorespiration rates between C_3 and C_4 plants.

Response to elevated CO_2 concentration

Increase in carbon dioxide concentration causes an increase in photosynthesis rate in both C_3 and C4 plants up to a certain CO_2 concentration, which is variable with crop species. But very high CO_2 concentration causes reduction in leaf photosynthesis due to partial closure of stomata. The response of C_3 plants to elevated CO_2 concentration for carbon fixation is more than that of C_4 plants. It is because of the reason that at elevated CO_2 concentration, the ratio of chloroplastic CO_2: O_2 increases causing more carbon dioxide molecules competing with oxygen for reaction site of Rubisco resulting in increased photosynthesis and reduced respiration leading to high net photosynthesis rate in C_3 plants. Low response of C_4 plants to elevated CO_2 concentration is because of two reasons:

- The enzyme PEP carboxylase has about 100 times more affinity to CO_2 than Rubisco and therefore, PEP Case can react well even with low amount of CO_2 present in the chloroplast. This enzyme is incapable of reacting with oxygen. Therefore, increased ratio of CO_2: O_2 in mesophyll cells has low utility.
- The carbon dioxide liberated from C_4 acids is pumped into bundle sheath cells (where Rubisco is present) causing CO_2 concentration much higher than atmospheric concentration. Therefore, increased atmospheric carbon dioxide concentrations do not make proportional increase in CO_2 concentration near the site of action of Rubisco enzyme in C_4 plants.

Differential response of C_3 and C_4 plants to elevated carbon dioxide concentration is reported by Kimball *et al.* (2002) on the basis of a large number of FACE (Free Air CO_2 enrichment) experiments. They reported higher increase in photosynthesis of C_3 species than C_4 species in FACE experiments. They also found that peak leaf area index and crop yields increase in C_3 plants under elevated CO_2 concentration but in case of sorghum, a C_4 plant, both these parameters reduced. The decrease in stomatal conductance and evapo-transpiration under elevated CO_2 concentration may be due to partial stomatal closure at elevated levels of carbon dioxide. The benefit of CO_2 enrichments are more pronounced in a short period study but in long term, the effects on photosynthesis is less, may be due to accumulation of photosynthates is source leaf because of less demand by sink.

Impact of climate change

Impact assessment of climate change on crop productivity is very difficult due to complicity of the response of different plants processes to changes in temperature and carbon dioxide concentration. The rise in carbon dioxide concentration may favor C_3 photosynthesis because rise in atmospheric CO_2 would not reach the level in foreseeable future at which photosynthesis is reduced due to stomatal closure. The C_4 plants being less responsive to elevated CO_2 concentration will have less or no improvement in their photosynthetic rate. The rise in temperature may have both beneficial and harmful effects on crop photosynthesis depending upon location, crop species, crop growth stage and level of temperature. The temperate reasons, the species and crop growth stages, which require warm climate may benefit from temperature rise. On the other hand, crops, which are adapted for low temperature and crops grown in tropical climate may be adversely affected due to rise in temperature. The productivity of crops will depend upon relatives gain in photosynthesis compared to respiratory loss. The latter is to play more important role because photosynthetic gain is limited by day light but increase in temperature associated respiration continues for whole of the crop life cycle. The plants like any other organism, have inbuilt mechanism to make adjustments in their different processes to enable to survive in a given set of conditions (acclimation). How and to what extent plants will adapt to environmental change, is not properly under stood. Therefore, the effects of short term (hours and crop season) experiments may not hold true in long term of decades on century changes in climate which is a slow but continuous change. Rice crop is sensitive to changes in temperature and carbon dioxide concentration (Hundal and Kaur 2002). Being a C_3 plant, rice holds an edge over C_4 plants due to increase in photosynthetic rates under expected enhanced CO_2 concentrations. The results of the simulation study for interactive effects of increasing temperature and CO_2 concentration revealed that the adverse effect of increase in temperature on growth and yield of crop was counter-balanced by favorable effect of increasing CO_2 levels up to some particular combination. With temperature increase of 1.0°C from normal, CO_2 concentration of only more than 500 ppm was able to nullify the negative deviations in growth and yield, but when temperature increased by 2.0°C from normal, even 600 ppm CO_2 was unable to nullify the adverse effect of temperature.

Effect of elevated CO_2 on nutrient cycling

Higher biomass productivity by plants under elevated CO_2 will ultimately increase organic matter inputs to soils. Increased soil carbon under elevated CO_2 could lead to higher soil microbial biomass and immobilization of nutrients. This will have negative effect on plant growth and has been demonstrated in a pot CO_2 experiment where microbial biomass N increased and plant responses to elevated CO_2 were negative (Diaz *et al*., 1993) mainly due to increased input of high C:N compounds to soils. On the other hand, extra C inputs to soils can increase microbial activity and thus enhance the mineralization of organic matter. Its positive effect on plant growth has been proposed by Zak *et al.* (1993). Two different mechanisms may explain these observations: First, microbial N may have been primed by extra C inputs under elevated CO_2 (mechanism proposed by Zak *et al.* 1993), second, increased soil moisture at elevated CO_2 may have led to increased N mineralization, at least in water limited ecosystems. Microbial immobilization of extra N under elevated CO_2 may be restricted to systems where N supply is abundant and nutrient cycles are not in equilibrium with plant demand (Niklaus and Korner 1996 and Hu *et al.*, 1999). Phosphorus and sulphur may respond to elevated CO_2 in a similar way as that of N because increases in soil microbial biomass will also be accompanied by the immobilization of these nutrients and the decomposition of soil organic matter will release the mineral nutrients that it contained. Higher soil moisture has been reported in many ecosystems exposed to elevated CO_2 (Morgan *et al.,* 2004b) and this will enhance the leaching of nutrients because more water will drain through the soil profile, when saturation is exceeded. Korner and Arnone (1992) observed increased NO_3^- leaching from tropical communities. While many studies reported decrease in NO_3^- leaching like Torbert *et al.* (1996) found decreased NO_3^- concentrations below the rooting zone. Niklaus *et al.* (2001b) observed reductions in soil NO_3^- concentrations in calcareous grassland communities exposed to elevated CO_2 for several years. Soil NO_3^- concentrations are regulated by many interacting processes, including nitrification and denitrification, immobilization of NH_4^+ and NO_3^- by soil microbes, and rooting patterns and root uptake of NH_4^+ and NO_3^-. Therefore, predictions are difficult, but a principal control is certainly plant uptake of mineral N, which will reduce NH_4^+ available for nitrification or remove the NO_3^- produced.

Effect of elevated temperature and rainfall on agriculture

Temperature is a very important factor affecting crop productivity right from seed germination to harvest all phonological stages of crop are affected by temperature. Any variation in temperature will affect crop productivity adversely. Singh *et al* (2009) concluded that a decline in rainfall with anticipated thermal stress (maximum temperature is increased by 0.18 ^{0}C and minimum temperature is increased by 1.58 ^{0}C leads, on an average, to a reduction in crop yield by nearly 5% for every 10% decline. The positive effects of elevated CO_2 almost cancel out with enhanced thermal stress (maximum temperature is increased by 0.28 ^{0}C and minimum temperature is increased by 2.58 ^{0}C and reduction in rainfall by 40 and 50% such that soybean yield is up by only 0.1% and down by 6%, respectively. This suggests that significantly deficient monsoon rainfall conditions combined with thermal stress should adversely affect the positive effect of elevated CO_2 on the soybean crop in Madhya Pradesh, India. Khetarpal *et al.* (2009) observed the significant increase in rate of photosynthesis and reduction in stomatal conductance was observed in both the chickpea cultivars grown at high temperature. Pusa 1053 showed significant increase (64 %) in rate of photosynthesis during flowering stage. Similarly, Pusa 1108 plants showed 15.5 and 24.3% increase in rate of photosynthesis during vegetative and podding stages. Stomatal conductance decreased in both the cultivars under elevated temperature significantly at all the growth stages. Among two cultivars, Pusa 1053 showed higher reductions (43%) in stomatal conductance during vegetative stage. The response of crop species to temperature depends upon the temperature optima of photosynthesis, growth and yield. When the level of temperature is below the optimum for photosynthesis, a small increase in temperature can greatly increase the rate of photosynthesis and crop growth and the reverse is true when the level of temperature is near the maximum for growth and photosynthesis. The enhancement in photosynthesis rate under elevated temperature indicated that ambient temperature during the crop growth period was below optimum for photosynthesis. As a result, exposure of the plants to high temperature increased rate of photosynthesis.

Field studies conducted by Dhiman *et al.* (1985) and Saini and Nanda (1987) indicated that increased temperature hastened the rate of senescence resulting in reduced LAI and total biomass in wheat, the decreased crop duration with increased temperature resulted in reduction in gain yield. Hundal and Kaur (1995) reported that maximum LAI in wheat decreased by 4.5 to 33.8 %, in rice by 1.5 to15.9 % and in groundnut by 1.2 to 5.3 % when the temperature increased from 0.5 to3.0^{o}C above normal, the study further revealed that with similar increase in temperature the grain yield of wheat, rice and maize declined by 5.5 to 25.7%, 2.4 to 25.1% and 7.4 to 21.4%, respectively from the normal yields. In another study conducted by Kaur *et al.* (2007) using CERES wheat model to assess the effect of intra seasonal increase in temperature from normal on yield of wheat sown on different dates revealed that in general an increase in temperature from mid February to mid March severely affected the yield of early, normal and late sown wheat. Mathauda *et al.* (2000) validate the CERES-Rice model under Punjab conditions and give the % deviation over normal scenario. The results showed a decline in crop duration, grains m^{-2}, grain yield, maximum LAI, grains per ear, biomass and straw yield with each 0.5 ^{0}C increase in temperature over the normal during the crop season. Under the warm climatic scenarios, the reduced source size (leaf area) coupled with poor sink strength (as depicted by the number of grains per ear) reduced number of effective tillers (as indicated through lesser number of grains m^{-2}) and shorter period of harvesting solar radiation (crop duration) resulted in considerable decline in biomass and grain yield of rice crop over the normal (Table 4). Jalota and Panigrahy (2009) suggested that amongst the three cropping systems, cotton-wheat will be affected more adversely than maize-wheat and rice-wheat systems. The adverse effect of increased temperature was more for maximum temperature than minimum temperature. Though increase CO_2 would increase the crop productivity but the magnitude of increase in crop yields was less than that of decrease by the increased temperature.

Interactive effect of changing climatic factors on crop production

The ultimate productivity of crops is determined by the interaction of genotypes, soil constituents, water, temperature, day length etc. According to Yoshida and Parao (1976) 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. 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 spikelets and hence increased the grain yield. Solar radiation had positive influence on grain filling during the ripening period. The simulation results indicate that warm climate with decreasing radiation levels will affect the growth and yield of cereal crops. However, the harmful effects of increasing temperature on growth and yield are likely to be counter-balanced by the increasing levels of CO_2 concentrations to some extent in the near future (Hundal and Kaur 1996 a,b).

Table 4. Effect of CO_2 and temperature on LAI of Rice

Temperature	CO_2 (ppm)			
	Normal (330)	400	500	600
Deviation from normal (%)				
Normal	5.22*	+1.9	+8.5	+11.0
+ 0.5^{0}C	-5.5	-1.9	+2.5	+6.6
+ 1.0^{0}C	-9.3	-6.1	-4.0	+1.7
+ 1.5^{0}C	-9.8	-9.1	-5.7	-1.7
+ 2.0^{0}C	-12.3	-11.9	-7.8	-5.5

Source: Hundal and Kaur (1996a,b)

Abrol *et al.* (1991) observed that in India the adverse effects of 1-2^{o}C rise in temperature could be absorbed with 5-10 per cent increase in precipitation. The grain yield 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. All India estimates of production based on current relative contribution of different states in total production, showed decline in production from the current levels by 3.16 and 13.72 % in the year 2020 and 2050, respectively. Currently the winters are severe in Punjab, Haryana and western UP witnessing frosting in December and January. In future climate scenarios warming may ease the chilling conditions in these regions to favour potato productivity, while in other regions with cooler winter season the warming from current levels may prove detrimental (Singh and Lal 2009). Mahi (1996) found that the maximum LAI, biomass and grain yield of wheat and rice declined when the radiation decreased by 10 per cent from the normal but increased when the radiation was enhanced by 10 per cent from the normal. The simulation results suggest that the growth and yield of wheat and rice would be influenced by increasing temperature. The adverse affects generated by high temperature scenario may be lessened to some extent by decrease in radiation amounts. But this aspect is still uncertain because the radiation is expected to be on the lower side under the influence of greenhouse effect. In the Punjab state, there are indications that the amount of radiation is likely to decrease. As a result, the production of wheat and rice may be adversely affected depending upon the degree of change in the coming years. The past increase in CO_2 experienced to date and the projections of its increase in the future will no doubt counter balance the negative effects of rise in temperature on the crop productivity.

Effect of increased temperature and rainfall on nutrient cycling

Elevated CO_2 concentration along with other green house active atmospheric gases, will lead to higher mean atmospheric temperatures and altered precipitation patterns (IPCC, 2001). Goncalves and Carlyle (1994) studied N mineralization in vitro at different temperatures and soil moisture contents. The reduction in mineralization rate when reducing soil moisture from 60 to 10% of field capacity was much larger relatively at 25°C (≈70%) than at 5°C (≈50%). Warming both experimentally and naturally, is accompanied by increased evapotranspiration and, therefore, decreased soil moisture and plant water availability (Luo *et al.,* 2001), which results in a further reduction of microbial activity. Contrary to this, several whole-ecosystem studies have shown that increased air temperatures can actually result in decreased soil temperatures (Coulson *et al.,* 1993, Robinson *et al.,* 1995, Wookey *et al.,* 1993). It could be due to increased biomass of plants at elevated ambient temperatures can effectively insulate soils from solar radiation, further, taller species will absorb solar radiation farther off the ground and convective heating of soils will effectively be reduced. Lukewille and Wright (1997) heated forest floor by 3 to 5°C using electric cables and found increased NO_3^- and NH_4^+ in runoff. Joslin and Wolfe (1993) found higher soil NO_3^-, Mg and Al concentrations at the warmer spots. High temperatures during summer can increase evapotranspiration particularly in areas with relatively dry climate, drier soils may have higher rates of erosion by wind and rain, also, the frequency of droughts may increase, further enhancing erosive losses (Schar *et al.,* 2004). Plant canopies reduce erosive power of rain by interception, subsurface roots hold the soil in place, and crop residues and surface mulch reduce rill erosion rates (Nearing *et al.,* 2004). Increased rainfall may also increase erosion because of increased amount of precipitation and due to extreme rainfall events as is predicted for many areas (IPCC 2001). Soil erosion by rain is determined by intensity of rain, a 1.5 to 2.0% increase in erosion rates can be expected by a percent increase in precipitation as reported by Nearing *et al.* (2004).

Effect of climate change on water requirement of plants

Warmer air temperatures will influence leaf evaporation by affecting vapour pressure diffusion because warmer air has a greater water vapor holding capacity so it will increase the evaporative gradient at the leaf surface (Polley 2002). It is possible that vapour pressure diffusion will rise with global warming, particularly in areas where precipitation is expected to decrease. Allen *et al.* (2003) found in soybean grown in outdoor chambers that elevated CO_2 reduced stomatal conductance, by 33% at an average growth temperature of 27°C, and by only 17 at 40°C. Increases in leaf area index can balance any changes that reduced canopy evaporation has on canopy water use, while having the potential to reduce soil evaporation. In field grown, wheat and sorghum crops exposed to FACE, ET decreased by 9 and 7%, respectively, relative to control plots (Conley *et al.*, 2001; Grant *et al.*, 2001). In a nutrient-poor, water-limited grassland system, there were small reductions in ET at elevated CO_2. These small but insignificant differences in ET accumulated over time, leading to marginal but significant water savings at elevated CO_2 (Niklaus *et al.*, 1998; Niklaus and Korner 2004). Wilson *et al.* (1999) modeled ET for soybean and maize and found that, at the simplest level with no feedback operating, ET was reduced by 15.1 and 24.7% in soybean and maize, respectively, at double ambient (CO_2). With maximum complexity accounting for atmospheric feedbacks, soil fluxes, and physiological responses, ET decreased by 5.4 and 8.6%, in soybean and maize respectively, at high CO_2. Introduction of water stress to the model increased the reductions in ET for both crops. Grant *et al.* (2001) reported from a wheat experiment, in which FACE decreased ET by 7 and 19% under high and low N supplies, respectively. In contrast, soil water stress can enhance the reductions in ET under CO_2 enrichment as has been observed for sorghum (Conley *et al* 2001). Warmer air temperatures can nullify the effects of elevated CO_2 on ET. Allen *et al.* (2003) found in soybean grow in outdoor chambers that double ambient CO_2 reduced ET by an average of 9 at 23°C, while high CO_2 had no effect on ET above 35°C. In a nut shell, the available data suggests that elevated CO_2 reduces ET of well-watered canopies.

Effect of climate change on weeds

Apart from the direct CO_2 fertilization effect, climatic change, particularly precipitation and temperature, will have effects on weed biology. Temperature and precipitation are primary abiotic factors, which control distribution of vegetation on the globe, and as such will impact the geographical distribution of weeds with subsequent effects on their growth, reproduction, and competitive abilities. Increasing temperature may mean expansion of weeds into higher latitudes or higher altitudes. Many of the weeds associated with warm-season crops originated in tropical or warm temperature areas; consequently, northward expansion of these weeds may accelerate with warming (Patterson 1993, Rahman and Wardle 1990). Patterson *et al.* (1979) found that in itchgrass (*Rottboelliia cochinchinensis*) a warming of 3°C (day night temperature increase from 26/20 to 29/23°C) increased biomass and leaf area by 88 and 68%, respectively. Patterson (1995 a,b) reported a Northward expansion of weeds, such as *Imperata cylindrica* and witchweed (*Striga asiatica*), due to warming. However warming may restrict the southern expansion of some plants such as wild proso millet (*Panicum miliaceum*) due to increased competition (Patterson *et al.*, 1986). Most of the crop species are C_3 plants, while many weed species are C_4 plants. C_3 plants are expected to benefit more from elevated CO_2 than C_4 plants which suggests that crops will gain a competitive advantage over most weeds. This could result in changes in herbicide efficacy because at elevated temperatures, metabolic activity tend to increase uptake, translocation, and efficacy of many herbicides (Patterson *et al.*,1999), while moisture deficit, especially when severe, tends to decrease efficacy of post-emergence herbicides, which generally perform good when plants are actively growing. Ziska *et al.* (1999) found that elevated CO_2 levels reduced the efficacy of the widely used herbicide glyphosate. In controlled-environment studies, herbicide efficacy was mostly reduced by elevated CO_2, and effects were dependent on the mode of action of herbicides, on weed species, and on competition. Double-ambient CO_2 caused a decrease of 57% in efficacy of the herbicide fluazifopbutyl + fenoxyprop (blocks the activity of (AC Case) applied to *Avena fatua* (C_3), no effects of elevated CO_2 were found when the herbicide was applied to *S. viridis* (C_4) (Archambault *et al* 2001). Differences in growth response and effects of CO_2 on herbicide efficacy between *A. fatua* (C_3) and *S. viridis* (C_4) serve to illustrate the complexity of the issue. Coupland (1986) studied the effects of environmental conditions on herbicide efficacy on *Agropyron repens* and found that increased light, temperature and humidity immediately following application increased the efficacy of fluazifop-butyl, but that prolonged exposure of plants to increased temperature and light decreased efficacy. In this study, increased daytime temperature also caused decreased herbicide efficacy. Herbicide efficacy was found to increase, decrease, or remain the same when plants were subjected to changed environmental conditions (climate change) and efficacy changes were species specific.

Effect of climate change on fertilizer requirement

The total amount of N-fertilizer required by C_3 crops to support optimal productivity at elevated CO_2 concentration is likely to remain same, despite the increase in biomass (Poorter and Navas 2003). This view is supported by results of wheat (Adamsen *et al.*, 2005) and for sorghum (Torbert *et al.*, 2004). While an increase in losses of nitrogen can leads to an increase in demand of its fertilizers, secondly in areas where favorable environmental conditions will be created due to altered rainfall and temperature regimes the need for fertilizers may increase.

Effect of increased CO_2 concentration on crops

Carbon dioxide is vital for photosynthesis and hence for plant growth. An increase in atmospheric CO_2 concentration affects agricultural production by climate change and change in photosynthesis and transpiration rate. The direct effect of increased concentrations of CO_2 are generally beneficial to vegetation (Farquhar 1997), especially for C_3 plants, as increased levels leads to higher assimilation rates and to an increase in stomatal resistance resulting in a decline in transpiration and improved WUE of crops. Simulation studies have been conducted to study the effect of increased concentration of CO_2 on yield of crops. Lal *et al* (1998) found that under elevated CO_2 levels, yield of rice and wheat increased by 15 and 28%, respectively for a doubling in CO_2 concentration in NW India. Hundal and Kaur (1996a,b) reported that compared to base level of 330 ppm CO_2, grain yield of rice would increase by 1.5, 6.6 and 8.7% with enhanced CO_2 concentrations of 400, 500 and 600 ppm, respectively (Table 5).

Table 5. Change in wheat yield due to varying CO_2 concentration under optimal and sub optimal moisture conditions

CO_2 concentration (ppm)	Grain yield (kg/ha)		% change from base optimal and suboptimal yield	
	Optimal	Sub-optimal	Optimal	Sub-optimal
330 (Base value)	3837	3112	-	-
440	4630	3695	21	19
550	5687	4327	48	39
660	6465	4876	68	57

Source: Hundal and Kaur (1996a,b)

Effect of climate change on rice-wheat system productivity

Climate change may have serious direct and indirect effects on the rice-wheat system and food security of India. This may be aggravated by water scarcity, drought, flood, and decline in soil organic C content. Simulation models for rice production indicate a reduction in yield of about 5% per degree rise in mean temperature above 32°C (Matthews *et al.,* 1995). This would counter balance any increase in yield due to increased CO_2 concentration. Rice is sensitive to hot temperature at anthesis, sterility in some varieties occurs if temperatures exceed 35°C at anthesis for only about one hour (Yoshida 1981). At anthesis, spikelet fertility declines from 90 to 20% after only 2 hour exposure to 38°C, and to 0% by less than one hour exposure to 41°C. The critical temperature for spikelet fertility (defined as when fertility exceeds 80%) varies between genotypes, but it is about 32-36°C (Yoshida 1981). Below 20°C and above about 32°C, spikelet sterility becomes a major factor, even if growth is satisfactory. Rao and Sinha (1994) showed that higher temperatures and reduced radiation associated with increased cloudiness caused spikelet sterility and reduced yields 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 of rice.

Hundal and Kaur (1996a,b) reported that, if all other climate variables remain constant, a temperature increase of 1, 2, and 3°C would reduce the grain yield of rice by 5.4, 7.4 and 25.1%, respectively. Matthews *et al.* (1997) suggested that rice production in the Asian region may decline by 3.8% under changed climate. Lal *et al.* (1998) observed that, under elevated CO_2 yields of rice increased significantly (28% for a doubling of CO_2), however, 2°C increase in temperature canceled out the positive effect of elevated CO_2 on rice. Peng *et al.* (2004) reported that rice yield declined by 10% for each 1°C increase in growing season minimum temperature in the dry season, whereas, the effect of maximum temperature was insignificant. Zachrias *et al.* (2010) stated that the warmer temperature hastens crop development, shortens the growth period and thus finally lowers the grain yield. Impact of high temperature on crop growth and yield is largely determined by the duration and coincidence of it with sensitive crop growth phase. Period from panicle initiation to flowering stage is found to be more sensitive to high temperature stress in wheat and rice. Exposure to high temperature from seedling stage to panicle initiation stage affected yield predominantly causing tiller mortality and reduced number of spikes. Coincidence of high temperature stress with panicle initiation to flowering phase of crop affect grain yield by reducing dry matter accumulation, productive tillers, number of spikes, grain weight and increased floret sterility. In case crop is exposed to heat stress from flowering to maturity, then the reduction in yield is predominantly caused by floret sterility leading to reduced number of grains per spike and also due to reduced grain weight. Effects of climate change on wheat production include reduced grain yield over most of India, with the greatest impacts in lower potential areas such as the eastern IGP (Ortiz *et al.*, 2008). Physiological traits that are associated with wheat yield in heat-prone environments are canopy temperature depression, membrane thermostability, leaf chlorophyll content during grain filling, leaf conductance and photosynthesis and senescence (Reynolds *et al.*, 1998). Grain growth is shorter with heat stress, thereby influencing grain filling (Wardlaw *et al.,* 1980) and resulting in lower yield. Wheat cultivars capable of maintaining high test weight under heat stress are more tolerant to high temperature (Reynolds *et al.,* 1994). Hundal and Kaur (1996a,b) observed that in Punjab (India), a temperature increase of 1, 2 and 3°C from present-day conditions, would reduce the grain yield of wheat by 8.1, 18.7 and 25.7%, respectively.

Lal *et al.* (1998) found that under elevated CO_2, yields of wheat increased significantly (28% for a doubling of CO_2), however, 3°C rice in temperature nullified the positive effect of elevated CO_2 on wheat. Attri and Rathore (2003) observed an increase in yield of wheat to the extent of 29-37 and 16-28% for different genotype, under rainfed and irrigated conditions, respectively, for a temperature rise coupled with elevated CO_2 (T_{max} + 1.0°C, T_{min} + 1.5°C and 460 ppm CO_2) compared with the current climate. An increase in temperature on the order of 3°C or more, however, canceled out the beneficial effects of elevated CO_2. The impact of modified climate was observed to be higher under rainfed conditions than under irrigated conditions for all genotypes. Aggarwal and Sinha (1993) conducted simulation studies to find the impact of climate change on wheat yields for several locations in India using a modeling approach the results indicated that, in northern India, a 1°C rise in the mean temperature had no significant effect on potential yields, though an increase of 2°C reduced potential grain yields at most place. In another study, Rao and Sinha (1994) using the CERES-Wheat model, showed that wheat yields were lower than those in the current climate, even with the beneficial effects of CO_2 on crop yield. Yield reductions were due to a shortening of the wheat growing season, resulting from an increase in temperature. Aggarwal and Mall (2002) observed that a 2°C increase resulted in a 15-17% decrease in grain yield of rice and wheat but, beyond that, the decrease was very high in wheat. The grain filling of wheat is seriously impaired by heat stress due to reductions in leaf and ear photosynthesis at high temperatures (Blum *et al.*, 1994). Samra and Singh (2005) studied the impact of temperature rise in March 2004 on the productivity of wheat. A temperature increase above normal ranged from 1 to 12°C in different parts of northern India, resulting in a wheat production loss of 4.6 million tonnes due to increased incidences of pests and diseases, and advanced maturity of wheat by 10-20 days further reduced grain weight. Pathak and Wassmann (2007) studied the impacts of rainfall variability on wheat yield in Northwest India and showed that the years with scarce rainfall resulted in only 34% (Ludhiana) and 35% (Delhi) of the baseline yield. In Ludhiana, high rainfall years resulted in 200% yield as compared with the baseline yield, whereas these years resulted in only 105% yield in Delhi.

Strategies to deal with changed climatic scenario

According to the recent IPCC assessment, agricultural production in South Asia could fall by 30% by 2050 if no action is taken to combat the effects of increasing temperatures and hydrologic changes (IPCC 2007). Adaptive options to deal with the impact of climate change are

1. Developing varieties tolerant to heat and salinity stress and resistant to flood and drought.
2. Modifying crop management practices.
3. Proper water management.
4. Adopting new resource-conserving technologies.

- Conservation tilling/zero tilling/ Zero tillage: It has many benefits like reduced water use, carbon sequestration, increases yield and income, reduced fuel consumption, reduced GHG emissions, more tolerant to heat stress.
- Laser-aided land leveling: It helps in reduced water use, efficient tractor use, reduced fuel consumption, reduced GHG emissions, increased area for cultivation.
- Direct drill seeding of rice: Its benefits are less requirement of water, saves time, postharvest soil conditions of field is better for succeeding crop, deeper root growth and better tolerance to water and heat stress, reduced methane emissions.
- Raised-bed planting: It has many advantages like less water use, improved drainage, better residue management, less lodging of crop, more tolerance to water stress.
- Improved farming systems with several crop rotations
- Residue recycling as retention on surface or incorporation
- Growing cover crops
- Judicious use of fertilizers & INM
- Site specific nutrient management
- Leaf colour chart for N management: Use of leaf colour chart can help in reducing fertilizer N requirement; reduce N loss and environmental pollution, reduced nitrous oxide emission.
- Water management/ conservation, irrigation
- Use of tensiometer: The use of tensiometer for irrigation scheduling in paddy can save considerable amount of irrigation water. There is need to shift from conventional practices to improved recommended practices.

5. Crop diversification. Diversification will help is efficient use of water, increased income and nutritional security, conserve soil fertility, reduce risk of crop failures.
6. Improving pest management by IPM.
7. Improved weather forecasts and weather based agro advisories.
8. Utilizing the indigenous technical knowledge of farmers

All these recommended practices have different level of potential of carbon sequestration given below:

Recommended practices	C sequestration potential (Mg C/ha/yr)
Conservation tillage	0.10-0.40
Winter cover crop	0.05-0.20
Soil fertility management	0.05-0.10
Elimination of summer fallow	0.05-0.20
Forages based rotation	0.05-0.20
Use of improved varieties	0.05-0.10
Organic amendments	0.20-0.30
Water table management/ irrigation	0.05-0.10

Some management options to mitigate climate change

- Minimum tillage or zero tillage with residue cover in surface for improving soil quality
- Cover cropping, in-situ residue management and restoration of degraded lands for soil moisture conservation and improved C-sequestration
- Agro-forestry with multipurpose trees, crops and animal components for improving hydrology and also creates green cover for carbon sequestration. Forestry has highest level to sequest more soil organic carbon stocks.
- Integrated farming systems and watershed development with animal, fishery and hedge row cropping for soil and moisture conservation and nutrient recycling.
- Screening short duration varieties for their drought resistance.
- Popularization of technologies like system of rice cultivation (SRI) and aerobic rice cultivation for water saving and mitigation of green house gas (GHG) emission.
- In-*situ* biomass management instead of biomass burning to reduce CO_2 emission and improve hydrology.
- Promotion of technologies that enhance biological N fixation and improve nutrient and water use efficiency to reduce N_2O emission and dependence on non-renewable energy.
- Change in planting dates and crop varieties are another adaptive measure to reduce impacts of climate change to some extent. For example, the Indian Agricultural Research Institute study 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.

Nutrient Management

- Precise N application (dose, time and place)
- Use of slow release N fertilizers or nitrification inhibitors
- Applying N when least susceptible to loss or prior to plant uptake
- Integrated nutrient management (INM) and Site-Specific Nutrient Management (SSNM) have the potential to mitigate effects of climate change

Water Management

Efficient water use leads to more grain and residue production which ultimately results in more carbon sequestration and reduces GHGs emission to a considerable level. Proper drainage improves the aeration in the soil and reduces the CH_4 and N_2O emission from rice fields.

Researchable issues identified for future

- Breeding for improved crop varieties with specific reference to growth and flowering phenology, photo sensitivity/insensitivity, stability in response to inputs viz., lodging resistant, optimum tillering, harvest index etc.
- Evolving efficient water and soil management practices in addition to identification of crops and varieties with high water use efficiency, dry matter conversion ratio, positive response to temperature extremes and elevated CO_2.
- Identifying new intercropping and novel farming system combinations including livestock and fisheries, which can

withstand predicted climate change situations and can be economically viable
- Identifying cost effective methods for reducing greenhouse gas emission from rice paddies and also from cropping systems with livestock components
- Promoting conservation agriculture practices especially in water harvesting, nutrient, pest and disease management

Conclusion

- Climate change is a reality.
- C_3 plants will be benefited more than C_4 plants at elevated CO_2.
- Weeds will become more competitive from carbon fertilization.
- Mitigation strategies need to be studied to meet the challenge posed by climate change on agriculture productivity
- Water management practices such as alternate wetting and drying, mid-season drainage helps in reducing CH_4 emission from rice fields
- Increase humidity and higher temperature will result in more infestation of diseases

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