CLIMATE CHANGE AND CROP PRODUCTION

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Abstract : Changes in climate can be expected to have significant impacts on crop yields through changes in green house gases (Co_2, methane, nitrous oxide, chlorofluorocarbons *etc*.), temperature and water availability. Scientific evidence about the seriousness of the climate threat to agriculture is now unambiguous, but the exact magnitude is uncertain because of complex interactions and feedback processes in the ecosystem and the economy. The increasing Co_2 concentration is posing a serious threat as it leads an increase in the average global temperature but the same has been positively correlated with increased biomass and yield particularly in C_3 plants. The purpose of mitigation is therefore to attempt a gradual reversal of the effects by the climate change and sustainable development. There are several mitigation and adaptation practices that can be effectively put to use to overcome the effects of climate change with desirable results.

Keywords: Bio-diversity, Climate change, Crop production, Greenhouse effect, Mitigation

INTRODUCTION

Rational use of natural resources *viz*. soil, water, climate and bio-diversity will determine the prospects of food and nutritional security in world in 21st century. During the last more than three decades, these resources have been stretched and over exploited to meet food, fibre and shelter requirements of burgeoning human and livestock population. Over-exploitation of water, soil and bio-diversity in the recent past has resulted in their degradation beyond expectations.

Climate change is a change in the statistical distribution of weather over periods of time that range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events over time (IPCC, 2001). Climate change is a complex alteration of climate, subtle and continuous, yet extremely important through its consequences on vegetation of various types that thrived under constant or relatively unchanged climates. At present, throughout the world, there exists a significant concern about the effects of climatic changes, as climate is one of the main determinants of agricultural production and it might cause variability in agricultural production. As climate pattern shifts, changes in the distribution of plant diseases and pests may also have adverse effects on agriculture. At the same time, agriculture proved to be one of the most adaptable human activities to varied climate conditions (Mendelson *et al*., 2001). In general, the tropical regions to be more vulnerable to climate change than the temperate regions for several reasons. (i) On the bio-physical side, temperate C_3 crops are likely to be more responsive to increasing levels of CO_2; (ii) The tropical crops are closer to their high-temperature optima and experience high temperature stress, despite lower projected amounts of warming; and (iii) insects and diseases, already much more prevalent in warmer and more humid regions, may become even more widespread (Varshneya, 2007)

Anthropogenic factors are the human activities that change the environment. In some cases, the chain of casuality of human influence on the climate is direct and ambiguous (for example, the effect of irrigation on local humidity) while in other instances it is less clear various hypothesis for human climate change have been argued for many years. Presently the scientific consensus on climate change is that human activity is very likely the causes for the rapid increase in global average temperature over the past several decades. Of most concern in these anthropogenic factors is the increase in Co_2 levels due to emissions from fossil fuel combustion, followed by aerosols (particulate matter in the atmosphere and cement manufacture, other factors include land use changes, ozone depletion, animals, agriculture use and deforestation are also of concern in the roles they play both separately and in conjunction with other factors affecting climate.

Green house effect: The green house effect is a natural feature of the climate system. Infact, without the atmosphere (and hence green house effect), the earth's average temperature would be approximately 33^oC colder than is observed currently. The atmosphere is more efficient at absorbing long wave radiation, which is then emitted both upward towards space and downward towards the earth. This downward emissions serves to heat the earth further.

This further warming reradiated is known as the green house effect. Some gases in the atmosphere are particularly good at absorbing the long wave radiation and are known as the green house gases (GHG).

Gases that contribute to the greenhouse effect include.

- **Water vapor:** The water vapours are most abundant green house gas, but importantly, it acts as a feedback to the climate. As Water vapors increase, the earth's atmosphere warms, but so does the vapors possibility of clouds and precipitation, making these some of the most important feedback mechanism to the green house effect.
- **Carbon dioxide (CO_2):** A minor but very important component of the atmosphere, Co_2 is released though natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning of fossil fuels. Humans have increased atmosphere Co_2 concentration three times since the beginning of industrial revolution. This is the most important long-lived forcing of climate change.
- **Methane:** A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock.
- **Nitrous Oxide:** A powerful green house gas that originates from the microbial breakdown of agricultural fertilizers, fossil-fuel combustion and biomass burning. Coal combustion is a major contributor of N_2O to the atmosphere.
- **Chloro-fluorocarbons** (CFCs): These are relatively inert class of manufactured industrial compounds containing carbon, fluorine and chlorine atoms. These compounds escape to the atmosphere where they destroy the stratospheric ozone layer that shields the earth from harmful ultra violet radiation. Their role in ozone depletion led to the first comprehensive international environmental treaty the Montréal protocol to phase out the use of CFCS. However they are also green house gases.

Table 1. Main green house and their global warming potential (IPCC, 2001)

Greenhouse gases	Chemical formula	Pre-industrial concentration	Concentration in 1994	Atmospheric lifetime (years)	Anthropogenic sources	Global warming potential (GWP)
Carbon dioxide	CO_2	278000 ppbv	358000 ppbv	Variable	Fossil fuel combustion, land use conversion, cement production	1
Methane	CH_4	700 ppbv	1721 ppbv	12.2	Fossil fuel, rice paddies, waste dumps, livestock	21
Nitrous oxide	N_2O	275 ppbv	311 ppbv	120	Fertilizers, industrial processes combustion	310
CFC-12	CCL_2F_2	0 ppbv	0.503 ppbv	102	Liquid coolants, foams	6200-7100
HCFC-22	$CHCLF_2$	0 ppbv	0.105 ppbv	121	Liquid coolants	1300-1400
Perfluoro-methane	CF_4	0 ppbv	0.070 ppbv	50,000	Production of almunium	6500
Sulphur Hexafluoride	SF6	0 ppbv	0.032 ppbv	3200	Dielectric fluid	23900

Consequences of Green house effect

The consequences of changing the natural atmospheric green house are difficult to predict, but certain effects seem likely.

- On average, earth will become warmer. Some regions may welcome warmer temperatures, but other may not.
- Warmer conditions will probably lead to more evaporation and precipitation. Overall, but

individual regions will vary some becoming wetter and other dryer.

- The observed warming over the 20th century was accompanied by a 10% increase in precipitation in the Northern Hemisphere and an increase in global seas-level of 4-8 inches.
- Mean while some crops and other plants may respond favorably to increased atmosphere Co_2 growing more vigorously and using water more efficiently. At the same time, higher temperatures and shifting climate pattern may change the areas where crops grow best and affect the makeup of natural plant communities.
- The climatic response to increasing green house gases has been assessed through various mathematical models. The surface air temperature due to Co_2 doubling as simulated by a variety of general atmospheric circulation models yields warming of order 4.2^{o}C. The green house gases induced warming for the period 1950 to 2030 will be 1.5 and 6.1^{o}C. An average rate of increase of global temperature during the next century is projected as 0.3^{o}C per decade with an uncertainty range of 0.2-0.3^{o}C (IPCC, 2007).

Two positive feedback effects of green house effect are that higher surface temperature causes more evaporation and thus higher water vapor concentrations and water vapor itself is an infra red absorber. The second effect is that higher surface temperatures will lead to more melting of snow and ice-cover on land and seas which energy instead of reflecting it back into space.

On the other hand, negative feed backs include the possibility that a higher surface temperature may lead to cloudiness and thus reduce incoming solar radiation. The cloudiness effect could lead to further warming in some circumstances as the clouds will also decrease the infra red heat loss from the surface.

Climate change and Agro ecosystem

The climate change will effect crop yields and cropping pattern due to direct effect of changes in atmospheric concentrations of green house gases in general and CO_2 in particular. Carbon dioxide is a perfect example of a change that could have both positive and negative effects. By now it is very clear that the atmosphere is being constantly enriched with Co_2 and is warmed up. However it is not so clear that how the expected rise in Co_2 level and air temperature will increase to affect the plant processes. If LAI increase with elevated Co_2 concentrations, the ET is expected to rise with further increase in temperature because increased temperature is associated with greater vapor pressure deficits, have greater moisture stress (Allen's, 1990). The occurrence of moisture stress during critical stages of crops like flowering and grain filling may further result in step reduction in post anthesis, photosynthesis and grain yield. Higher temperature also reduces plant development and shortens the growth period. Co_2 increase may affect the crop productivity directly and indirectly. Effects are both positive and negative.

It has been proved experimentally that for single leaf photosynthesis rate increase with increased Co_2 level especially in C_3 plant. When these experiments were extended to crop levels, it was found that increased Co_2 concentration to 600 ppm increased the number of tillers and branches and hence greater solar radiation interception. Further increased Co_2 reduced transpiration due to decreased stomatal aperture and may result in higher WUE (Allen's, 1990). Since those results were obtained from studies conducted in leaf chambers, green houses and growth chambers where other environmental factors were controlled at a desired level, these may not be applicable under field conditions.

The effect of global change on the soil conditions in relation to plant growth and crop production:

The main potential changes in soil forming factors (forcing variables) resulting directly from global change would be in organic matter supply from biomass, soil temperature regime and soil hydrology, the later because of shifts in rainfall zones as well as changes in potential evapo-transpiration. The important changes include.

- A gradual, continuing rise in atmospheric Co_2 concentration entailing increased photosynthetic rates and water use efficiencies of vegetation and crops hence increases in organic matter supplies to soils.
- Minor increases in soil temperatures in the tropics and sub-tropics; moderate increases and extended periods in which soils are warm enough for microbial activity (warmer than about 5^{o}C) in temperate and cold climates, parallel to the changes in air temperatures and vegetation zones (Emanual *et al*. 1985.)
- Minor increase in evapo-transpiration in the tropics to major increase in high latitudes caused both by temperature increase and by extension of the growing period.
- Increases in amount and in variability of rainfall in the tropics; possible decrease in rainfall in a band in the subtropics pole ward of the present descants; minor increases in amount and variability in temperate and cold regions. Peak rainfall intensities could increase in several regions.
- A gradual sea-level rise causing deeper and tender inundation in river and estuary basins and on levee back slopes, and brackish-water inundation leading to encroachment of vegetation that accumulate pyrite in soils near the coast.

Co_2 fertilization effect

Plant photosynthetic rates generally increase linearly with light across relatively low ranges of light intensity, and then the rates decrease until they reach an asymptotic maximum. Because of crowding and shading of many leaves, most crop canopies do not reach light saturation at full sunlight; that is, they would be able to respond to light bands well beyond full solar irradiance. Likewise, crop photosynthetic rates respond to increasing bands of Co_2 but then level off at higher concentration (around 700 µ mol/ mo1 or greater, depending upon species and other factors). However, leaf photosynthesis usually increases with temperature up to some maximum value, and then declines. Furthermore, temperature affects not only photosynthesis, but also respiration, growth and development phases as well as reproductive processes. Elevated Co_2 may have some effects on crop phenology, although stages of development are governed primarily by temperature, time and photoperiod. If dates of planting were to be changed because of green houses effect, then phenological phases of plants could be affected. For example, higher temperature could decrease yields by decreasing the duration of grain filling period or changes in photoperiod could shorten or lengthen the vegetative phase.

The Co_2 fertilization affect begins with enhanced photosynthetic Co_2 fixation. Non- structural carbohydrates tends to accumulate in leaves and other plant organs as starch soluble carbohydrates or polyfructosans, depending on species. In some cases, there may be feedback inhibition of photosynthesis associated with accumulation of non-structural carbohydrates. Increased photosynthetic accumulation, especially in lemma may be evidence that crop plant grown under Co_2 enrichment may not be fully adapted to take complete advantage of elevated Co_2. This may be because the Co_2 enriched plants do not have an adequate sink (inadequate growth capacity), or lack capacity to load phloem and translocate soluble carbohydrates. Improvement of photo assimilate utilization should be are goal of designing cultivars for the future (Hall and Allen, 1993).

Reproductive biomass growth as well as vegetative biomass are usually increased by elevated Co_2. However the harvest index under, or the ratio of seed yield to above ground biomass yield, is typically lower under elevated Co_2 conditions (Allen, 1991; Baker *et al*., 1989), which may also be evidence of large capacity to utilize completely the more abundant photo assimilate.

Under elevated Co_2, stomatal conductance in most species will decrease which may result in less transpirations per unit leaf area. However, leaf area index of some crops may also increase. The typical 40% reduction in stomatal conductances induced by a doubling of Co_2 has generally resulted in only a 10% (or less) reduction in crop canopy water use in chamber or field experiment conditions. Actual changes in crop evapotranspirations will be governed by the crop energy balance, as mitigated by stomatal conductance, leaf area index, crop structure and any change metrological factors.

Water-use efficiency (WUE) (ratio of Co_2 uptake to evapotranpiration) will increase under Co_2 conditions. This increase is caused more by increased photosynthesis than it is by a reduction of water loss through partially closed stomata. Thus, more biomass can be produced per unit of water used, although a crop would still require almost as water from sowing to final harvest. If temperature rises, however, the increased WUE caused by the Co_2 fertilization effect could be diminished or negated, unless planting dates can be changed to more favorable seasons.

Growth of plants under elevated Co_2 results in changes in partioning of photo assimilates to various plant organs over time. In soy bean, elevated Co_2 generally promoted greater carbon (dry matter) partitioning to supporting structure (stems, petioles and roots) than to the leaf lamina during vegetative stages of growth (Allen *et al*., 1991.) During reproductive stages, there tended to be lower relative partitioning to reproductive organs (pods) by plants under elevated Co_2.

Campbell *et al.* (1988) showed that soybean leaf exhibited higher photosynthetic rates when grown at 660 than 300 µ mol/ mol Co_2 when measured at common intercellular Co_2 concentrations. Furthermore, Campbell *et al. (*1988) measured rubisco activity and amount in leaves of soybean grown in Co_2 concentrations of 160, 220, 280, 330, 660 and 990 µ mol/mol. They found that rubisco activity was almost constant at 1.0 µ mol CO_2/min/mg soluble protein across this Co_2 treatment range. Leaf soluble protein was nearly constant at about g/m^2 with 55% being rubisco protein. Specific leaf weight increased across the 160 to 990 µ mol/mol Co_2 concentration range, so that rubisco activity and a leaf dry weight basis decreased.

Valle *et al.* (1985) found that midday maximum photosynthetic CO_2 uptake rates of soybean leaves ranged from 30 to 50 µ mol/m^2/s and 15 to 25 µ mol/m^2/s on plants grown at 660 and 330 µ mol/mol CO_2 respectively. Allen *et al.* (1990) reported that, at all light levels, leaf photosynthetic rates increased linearly with CO_2 concentration across the range of 330 to 800 µ mol/mol. Valle *et al.* (1985) used a Michaelis-Menten type of rectangular hyperbola to summarize photosynthetic responses of soybean leaves vs. CO_2 concentration. The plants had been grown at 330 and 660 µ mol/mol of CO_2 and then exposed to a wide range of CO_2 for a short period.

$Y=(Y_{max} \times [C])/([C]+K_m)+Y_i$ (4.1)

where Y is photosynthetic rate in µ mol CO_2/m^2/s; $[C_3]$ is CO_2 concentration in µ mol/mol; Y_i is the y-axis intercept at zero $[C_3]$, the apparent respiration rate, in µ mol CO_2/m^2/s; Y_{max} is the response limit of $(Y - Y_i)$ at very high [C], the asymptotic photosynthetic rate, in µ mol CO_2/m^2/s; K_m is the value of [C] where $(Y-Y_i)=Y_{max}/2$, the apparent Michaelis-Menten constant, in (µ mol/mol; and $_c$ is the calculated [C] intercept at zero Y, the CO_2

compensation point, μ mol/mol (not shown in this equation). The average parameters for responses at 330 and 660 μ mol/mol are given in Table 2. There was no obvious down regulation of soybean leaf photosynthesis in response to elevated CO_2; in fact, photosynthetic capacity was increased. Leaf quantum yield increased from 0.05 to 0.09 in the soybean leaves exposed to CO_2 of 330 and 660 μ mol/mol, respectively (Valle *et al.*, 1985).

Table 2. Average asymptotic maximum photosynthetic rate (Y_{max}) with respect to y-intercept parameter (Y_i), apparent Michaelis-Menten constant for CO_2 (K_m, and CO_2 compensation point (μ_c.) for leaves grown at two CO_2 treatments and subjected to different short-term CO_2 levels. Condensed from Valle *et al.* (1985).

Growth CO_2 treatment	**Y_{max} μ mol/m^2/s**	**K_m μ mol/mol**	**Y_i μ mol/m^2/s**	**μ_c μ mol/mol**
330	51.8	359	-7.8	63
660	126.6	1 133	-4,6	42

Means of Y_{max} and Y_i were significantly different, p = 0.05, by a t-test.

Thus, pre-dawn respiration rates were closely connected to the previous CO_2 fixation rates.

Soybean seed yield tended to decrease slightly with temperature over the day/night range of 26/19 to 36/29°C (Table 3). The number of seed per plant increased slightly with increase of both CO_2 and temperature. Mass per seed decreased sharply with increasing temperature. Although CO_2 enrichment resulted in increased seed yield and above-ground biomass, harvest index was decreased with both CO_2 and temperature (Baker *et al.*, 1989). The data of Table 3 show no tendency for the growth modification factor to increase with temperature for either seed yield or biomass accumulation.

Table 3. Seed yield, components of yield, total above-ground biomass and harvest index of soybean grown at two CO_2 concentrations and three temperatures in 1987 (adapted from Baker *et al.*, 1989)

CO_2 conc. (μ mol/mol)	Day/night temperature (°C)	Grain yield (g/plant)	Seed/plant (no./plant)	Seed mass (mg/seed)	Above-ground biomass (g/plant)	Harvest index
330	26/19	9.0	44.7	202	17.1	0.53
330	31/24	10.1	52.1	195	19.8	0.51
330	36/29	10.1	58.9	172	22.2	0.45
660	26/19	13.1	58.8	223	26.6	0.49
660	31/24	12.5	63.2	198	27.6	0.45
660	36/29	11.6	70.1	165	26.5	0.44
F-values						
CO_2 conc.	12.3**	11.4**	2.5*	NA	NA	
Temperature	0.0 NS	8.4**	106.2**	NA	NA	
CO_2 x Temperature	2.0 NS	0.1 NS	11.2**	NA	NA	

Effect of higher day and night temperature on yield

Gaseous emissions from human activities are substantially increasing the concentrations of atmosphere green house gases, particularly carbon dioxide, methane, chloro-fluro carbons and nitrous oxides. Global circulation models predict that this increased concentration of green house gases will increase world's average temperature. Under the business as usual scenario of the inter-governmental panel on climate change (IPCC), global mean temperatures will rise 0.3°C per decade during the next century with an uncertainty of 0.2 to 0.5 % (Houghton *et al.*, 1990). Thus global mean temperature should be 1°C above the present values by 2025 and 3°C above the present value by 2100. Although global circulation models do not agree as to the magnitude, most predict green house warming. There is also general agreement that global warming will be greater at higher latitudes than in the tropics. Different global circulation models have predicted the global warming effects will vary diurnally, seasonally and with altitude.

It is also possible that there will be an auto cathartic component to global warming. Photosynthesis and respiration of plants and microbes increase with temperature, especially in temperate latitudes. As respiration increases more with increased temperature than does photosynthesis, global warming is likely to increase the flux of Co_2 to the atmosphere which would constitute a positive feedback to global warming.

CERES-Rice and CERES-Wheat have been validated for commonly sown cultivars of rice and wheat under Ludhiana (Punjab) conditions. Since rice and wheat are grown under assured irrigated conditions in

Punjab, optimum (non-limiting) moisture conditions were assumed (Hundal and Prabhjyot, 2007). Both maximum and minimum temperatures were increased or decreased by 0.5, 1.0, 2.0 and 3.0 ^{o}C from normal while keeping the other climate variables constant. Heading as well as maturity of rice was not much affected by increase or decrease in temperatures of 1.0 ^{o}C from normal (Table 4), but with a decrease in temperature by 3.0 ^{o}C heading and maturity were delayed by 15 and 12 days respectively, from normal. On the other hand, anthesis and maturity of wheat revealed more drastic changes as the phenology was significantly advanced by increasing temperature, but was delayed by decreasing temperature (Table 4).

Table 4. Effect of temperature change from normal on deviations in phenology (days) of crops (Hundal and Prabhjyot, 2007).

	Temperature change (^{o}C)								
Phenological event	-3.0	-2.0	-1.0	-0.5	Normal temperature	+0.5	+1.0	+2.0	+3.0
Rice									
Heading	5	2	0	0	101*	0	0	1	4
Maturity	12	6	2	0	141*	1	1	1	5
Wheat									
Anthesis	25	17	8	3	95*	-3	-6	-12	-16
Maturity	22	15	8	4	135*	-3	-6	-12	-17

*Number of days after sowing

When the maximum temperature decreased by 0.25 to 1.0 ^{o}C from normal and minimum increased simultaneously from 1 to 3 ^{o}C from normal keeping the other climate variables constant, the phenology of rice and wheat was advanced by as much as 1-8 days (Table 5). In rice and wheat, when minimum temperature increased by 1.0 to 3.0 ^{o}C and maximum temperature decreased by -0.25 to -1.0 ^{o}C from normal, both the anthesis and maturity were advanced by upto 8 days from normal.

Table 5. Effect of increasing minimum temperature above normal and decreasing maximum temperature below normal on deviation in phenology (days) of crops (Hundal and Prabhjyot, 2007).

		Minimum Temperature change (^{o}C								
		+1.0			+2.0			+3.0		
		Maximum temperature change(^{o}C)			Maximum temperature change(^{o}C)			Maximum temperature change(^{o}C)		
	Normal (DAS)	-0.25	-0.5	-1.0	-0.25	-0.5	-1.0	-0.25	-0.5	-1.0
Phenological event										
Rice										
Heading	101	-1	-1	-2	-2	-3	-3	-4	-4	-4
Maturity	141	-2	-2	-3	-4	-5	-4	-7	-8	-8
Wheat										
Anthesis	95	-2	-2	0	-6	-4	-3	-8	-8	-6
Maturity	135	-1	-1	1	-5	-4	-3	-8	-7	-6

Adverse effects of elevated levels of Ultra-violet (UV)-B radiation and ozone (O_3) on crop productivity

Surface-level ultra violet (UV)-B radiation (280-320 nm) and ozone (O_3) are components of the global climate and any increase in their levels can led to adverse effects on crop growth and productivity on a broad geographic scale (Krupa and Kickert, 1993). Possible increase in surface UV-B radiation are attributed to the depletion of the beneficial stratospheric O_3 layer (Cicerone, 1987). On the other hand, increase in surface-levels of O_3 that in many regions are largely the result of photochemical oxidant pollution, or also part of the general increase in the concentrations of the so called ‘‘green house gases’’ in the context of climate change, it is therefore important to maintain a holistic view and recognize that UV-B and O_3 levels at the surface are only parts of the overall system of atmosphere processes and their products. (Runeekles and Krupa, 1994).

Table 6. Effect of elevated surface levels of UV-B radiation or O_3 on crops

Plant characteristic	Effect of elevated	
	UV-B	O_3
Photosynthesis	Reduced in may C_3 and C_4 species (at low light intensities	Decreased in most species
Leaf conductance	Reduced (at low light intensities)	Decreased in sensitive species
Water use efficiency	Reduced in most species	Decreased in sensitive species
Leaf area	Reduced in many species	Decreased in sensitive species
Plant characteristic	Effect of Elevated	
	UV-B	O_3
Flowering	Inhibited or stimulated	Decreased floral yield, fruit set and yield delayed fruit set
Crop maturation time	not affected	Decreased floral yield, fruit set and yield delayed fruit set

Recent cases of climate change in India

Drought of 2002:

The drought of 2002 was one of the severest droughts of the last 100 years. Overall rainfall deficiency for the country as a whole was 19% and 56% area received deficient rains. Out of 36 metrological sub-divisions in the country, 21 sub divisions received deficient and scantly rain. The month of July received 49% less rainfall than the long range average rainfall. Water storage in 71 major reservoirs was 33% less than the average of previous 410 years (Singh, 2008). About 21.5 million ha areas was not sown and 47 million ha of sown crop was damaged, with a food grain shortfall of more than 29 million tons. About 300 million people and 56% of the total geographical area were affected.

Cold waves (2002-03):

Severe and prolonged cold wave prevailed over many parts of northern and north-eastern part of India during the winter season of 2002-2003 which considerably affected the survival and productivity of seasonal and perennial crops (Singh, 2008). Except the southern region of the Indian Peninsula, most of the country, particularly the Indo-Gangetic Plains was affected by freezing. The cold day's injuries had severe impact on crops, fruit trees, fishery, livestock and even human beings. Extreme fluctuations beyond normal variation in temperature due to cosmic events and anthropogenic activities that alter cardinal points of crop growth stages are a major concern in agricultural management and production. During December 2002 to January, 2003 daily maximum and minimum temperatures at several places in north India remained unusually below the normal continuously for 3-4 weeks.

Heat wave of March 2004.

The impact of abnormal temperature rise in March, 2004 on several winter crops including wheat, mustard and vegetables. Daily maximum temperature showed abnormal rise than the normal temperature at various places like Srinagar (3-12 ^{o}C) followed by Palampur (8-10 ^{o}C), Hisar (2-10 ^{o}C), Ludhiana (3- 6 ^{o}C), Jammu (1-6 ^{o}C), Uttarakhand (1-5 ^{o}C) and Jaipur (1-5 ^{o}C). Even minimum temperature during this period was higher than normal in several places. As a result of which loss of 4.6 million tons on wheat production was recorded which was very close to the advanced predication of about 4.4 million tons (Singh, 2008). The wheat crop matured 10-20 days in advance of normal period with reduced 1000 grain or test weight. Sowing of peas was advanced by one month due to early melting of snow in Lahul valley, apples flowered 15 days early in Chamber district and there was poor formation and filling of pods of rapeseed and mustard in Himachal Pradesh. Linseed yield was reduced by 50 per cent.

Mitigation options for climate change

The possible approaches to reduce or mitigation human induced climate change are:

Global initiative on soil-carbon sequestration

The IPCC estimates that the reduction in the options of agricultural GHG mitigation is cost-competitive with non-agricultural options for achieving long-term climate objectives. The carbon sequestration from the soil could in fact take effect very quickly and is very cost effective in agriculture. A win-win approach could be achieved by paying farmers for carbon sequestration (building organic matter), which sets up a scenario where Co_2 is removed from the atmosphere (mitigation) higher organic matter levels in soil increase the agro-ecosystem residence (adaptation) and improved soil fertility leads to better yields (production and income generation). However, sequestration of Co_2 in soils is not included in the clean development mechanism (CDM) agreed to in Kyoto protocol. The FAO Should play a leading role in this process, including the establishment of this process, including the establishment of a global soil carbon sequestration initiative, entrusted with the promotion of agricultural technologies that restore carbon pools and soil quality (*e.g.* organic agriculture, conservation agriculture) and to create tools to measure, monitor and verify soil-carbon pools and fluxes of green house gas emissions (*viz.* nitrous oxide) from agricultural soils, including crop lands and pastures.

Reduction in emissions from deforestation and forest degradation in developing countries

As the UN agency with the mandate for forestry and a comprehensive programme covering all aspects of forestry as well as agriculture, FAO can play a leading role in

(1) Providing technical information and support for the development of methodological and policy options for reduction in emissions from deforestation and forest degradation in developing (REDD)
(2) Strengthening the capacity for countries undertaking REDD programmes, including development of systems for monitoring changes in forest carbon
(3) Addressing the underlying causes of deforestation and forest degradation rooted in both agriculture and forest sector. In addition, FAO can launch a comprehensive REDD support effort for the developing countries.

Reduce global warming or its effects by geo engineering

Geo-engineering is a large-scale schemes to manipulate the earth's climate and mitigate the effects of green house warming (Begley 1999, Schneider 2001). These include using fleets of large aircraft or large guns to release dust into the lower stratosphere and reflect sunlight back into space. Other proposals to reduce solar input to our planet would send billions of aluminized reflective ballons into the stratosphere. These schemes raise numerous questions regarding possible harmful effect on ecosystems. For example, reduced solar input, in addition to reduced solar input, in addition to reducing the green house effect, might reduce photosynthesis in crops and natural vegetation, reducing agricultural and forest productivity.

Enhance Natural Carbon Sinks

If natural of Co_2 could be enlarged, they would remove more Co_2 from the atmosphere. The ocean's role as a significant sink for Co_2 might be enhanced. Phytoplankton in the lighted surface layers of the Blean, assimilate dissolved Co_2, and through photosynthesis, convert it to organic carbon (biomass).

Forest carbon sinks could be enhanced. Trees, through photosynthesis, remove Co_2 from the atmosphere and store it as organic carbon until the trees die and decays, or is burned, releasing the carbon back into the atmosphere as Co_2. Planting a new tree could effectively effort some Co_2 emissions for the life of the tree, often 100 to 300 years, and large-scale reforestation could significantly reduce the rate Co_2 build up in the atmosphere. If we could double our current rate of reforestation each year, we could delay greenhouse warming for a decade or two, possibly long enough to develop alternative sources of energy (Botkin 1989).

Table 7. Ways to reduce house-gas emission (IPCC, 2007)

Sector	Key mitigation technologies and practices currently commercially available
Energy	Supply efficiency, fuel switching, nuclear power, renewable resources (hydro-power; solar, wind, geothermal aid bio-energy), combined heat and power, early applications of Co_2 capture and storage.
Transport	More fuel-efficient vehicles, hybrid vehicles, bio-fuels, modals shifts form road transport systems, cycling, walking, land use planning
Industry	More efficient electrical equipment, heat and power recovery, material recycling, control of non-Co_2 gas emissions.
Agriculture	Land management to increase soil carbon storage, restoration of degraded lands, improved rise cultivation techniques, improved nitrogen fertilizer application, dedicated energy crops.
Forests	A forestation, reforestation, forest management, reduced deforestation, use of forestry products for bio-energy
Waste	Land fill methane recovery incineration of waste with energy recovery, composing, recycling and waste minimization.

Crop/cropping system based technologies

These will be mainly centered on promoting the cultivation of crops and varieties that fit into new cropping systems and seasons, development of varieties with changed duration that can over winter the transient effects of change, release of varieties for high temperature, drought and submergence tolerance, evolving varieties which respond positively in growth and yield to high Co_2. Improved and novel agronomic and crop production prentices like adjustment of planting dates and the management of the plant spacing and input supply may help reduce the adverse effects of changes in some climatic parameters.

Development of resource conserving technologies

Use of resource conservation technologies like surface seeding or zero tillage not only restrict the release of soil carbon in the atmosphere but also sometimes help partially with stand the adverse climate, and provide better yield or stabilize it. For example, surface seeding or zero-tillage of upland corps after rice gives yields similar to that when planted under normal conventional tillage over a diverse set of soil conditions. However more research is needed for their applicability in the arid lands.

Diversified farming

A shift from role cropping to diversified farming system is highly warranted. Horticulture and agro forestry need to be given more encouragement where as in the dries western part of the arid lands greater emphasis is required on pasture or biomass development for the livestock, which becomes a major component of the individual farmers economy. Use of farm-level land in the more vulnerable arid areas should be optimized to sustain production and manage risk, rather than to increase productivity.

Policy tools for resource management on a sustainable basis

Enabling policies on crop insurance (especially to with stand the impact of drought and flood), subsides and pricing related to water and energy uses need to be strengthened at the earliest. Policies that would encourage farmers to enrich organic matter in the soil and thus improve the soil health need emphasis (*e.g.* financial compensation or incentive for green manuring).

Contingency crop planning

Since *kharif* cropping is a primary activities in the rain fed areas of arid lands, where monsoon variability plays a crucial role in production, contingency crop planning will require a greater attention in these areas long term strategic approaches are also needed to efficiently conserve and utilize rain water on the one hand and un season tactical approaches to mitigate the adverse effects of weather aberrations on the other. Some of the approaches are water management, crop-row management, nutrient management, selection of crop varieties, in-season drought management, choice of crops with changing sowing condition, supplemental irrigation.

CONCLUSION

The issues of climate change and its potential impact on agriculture have been a major research, topic in recent times. We need to emphasis on the potential interactions between the effects of climate change and ongoing economic interactions. Global warming is already underway and adapting strategies are now a matter of urging, especially for the most vulnerable poor countries. An appropriate climate policy should be to minimize the effects of climate change at farm, regional, national and international level.

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