Chapter 2
Climate Change, Climate Variability and Indian Agriculture: Impacts Vulnerability and Adaptation Strategies

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2.1 Introduction

Climate is changing naturally at its own pace, since the beginning of the evolution of earth, 4–5 billion years ago, but presently, it has gained momentum due to inadvertent anthropogenic disturbances. These changes may culminate in adverse impact on human health and the biosphere on which we depend. The multi-faceted interactions among the humans, microbes and the rest of the biosphere, have started reflecting an increase in the concentration of greenhouse gases (GHGs) i.e. CO_2, CH_4 and N_2O, causing warming across the globe along with other cascading consequences in the form of shift in rainfall pattern, melting of ice, rise in sea level etc. The above multifarious interactions among atmospheric composition, climate change and human, plant and animal health need to be scrutinized and probable solutions to the undesirable changes may be sought.

Vulnerability is the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed as well as the system's sensitivity and adaptive capacity. Vulnerability to climate change varies across regions, sectors, and social groups. Understanding the regional and local dimensions of vulnerability is essential to develop appropriate and targeted adaptation efforts. At the same time, such efforts must recognise that climate change impacts will not be felt in isolation, but in the context of multiple stresses. In particular, the dramatic economic and social changes associated with globalisation themselves present new risks as well as opportunities.

Research on the impact of climate change and vulnerability on agriculture is a high priority in India as the impact, if it follows the predictions, is expected to be widespread and severe. Developing the ability to confidently estimate the impacts

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of climate change on agriculture is critically important. If ever achieved, it could provide the global information needed to help farmers develop their own long-range response to climate change. Fortunately, we are very near to having such a capability, and it may take 5–7 years to substantially improve the resolution and accuracy of the climate model and evaluate the implications for agriculture.

Changes in the atmospheric chemistry have increased during last few decades due to the heightened anthropogenic activities. Global negotiation have been under way for sometime to reduce the emissions of greenhouses gases to 1990 level, but the success of these endeavors are less certain today due to increasing reluctance of the major contributors to change. Considering the business as usual scenario, CO_2 is projected to increase at the rate of 1.8 ppm per year, reaching 397–416 ppm by 2010 and 605–755 by 2070 (Watson et al. 1998). This along with changes in other greenhouses gases is likely to result in a temperature increase of earth's surface and atmosphere.

2.2 Indian Agriculture and Climate Change

Agriculture sector alone represents 23 per cent of India's Gross National Product (GNP), plays a crucial role in the country's development and shall continue to occupy an important place in the national economy. It sustains the livelihood of nearly 70% of the population. It seems obvious that any significant change in climate on a global scale will impact local agriculture, and therefore affect the world's food supply. Considerable studies have been carried out to investigate how farming might be affected in the different regions. Several uncertainties limit the accuracy of current projections. One relates to the degree of temperature increase and its geographic distribution. Another pertains to the concomitant changes likely to occur in the precipitation patterns that determine the water supply to the crops, and the evaporative demand imposed on the crops in carbon dioxide enriched atmosphere. The problems of predicting the future course of agriculture in the changing world are compounded by the fundamental complexity of natural agricultural systems, and socio-economic systems governing the world food supply and demand. Many climatologists predict a significant global warning in the coming decades due to rising atmospheric carbon dioxide and other green house gases. As a consequence, major changes in the hydrological regimes have been also forecast to occur. Changes in the temperature, solar radiation, and precipitation will have an effect on crop productivity and livestock agriculture. Climate change will also have an economic impact on agriculture, including changes in farm profitability, prices, supply, demand, trade and regional comparative advantages. The magnitude and geographical distribution of such climate induced changes may affect our ability to expand the food production area as required to feed the burgeoning population of more than 10,000 million people projected for the middle of the next century.

Agriculture is sensitive to short-term changes in weather and to seasonal, annual and longer-term variations in climate. For the long-term changes, agriculture is able to tolerate moderate variations in the climatic mean. Changes beyond these bands of tolerance may require shifts in cultivars and crops, new technologies and infrastructure or ultimately conversion to different land uses. Crop yield is the culmination of a diversified range of factors. The variations in the meteorological parameters are more of transitory in nature and have paramount influence on the agricultural systems, although other parameters, like soil characteristic, seed genetics, pest and disease and agronomic practices also do impact crop yields. Among these factors, pest and diseases cause a significant loss to world food production under different climatic conditions. Development and distribution of pest and diseases are governed by temperature patterns, rainfall or humidity and seasonal length to a great extent. Especially, winter temperatures are important for the survival of pest and studies have shown that increase in temperature accelerates the development of pests in general. Pest-crop interaction will be also directly affected by the rising CO_2 levels through the alteration of host plant attributes, such as C/N ratios and secondary plant nutrient chemistry. In terms of crop production, these fluctuations must be taken into the account while planning agricultural operations. The climate elements which affect the plant growth and development, hence the agriculture as a whole, are carbon dioxide concentration, temperature, radiation, precipitation and humidity.

Analysis of the food grains production/productivity data for the last few decades reveals a tremendous increase in yield, but it appears that negative impact of vagaries of monsoon has been large throughout the period. In this context, a number of questions need to be addressed as to determine the nature of variability of important weather events, particularly the rainfall received in a season/year as well its distribution within the season. These observations need to be coupled to management practices, which are tailored to the climate variability of the region, such as optimal time of sowing, level of pesticides and fertilizer application.

The mean temperature in India is projected to increase by 0.1–0.3°C in kharif and 0.3–0.7°C during rabi by 2010 and by 0.4–2.0°C during kharif and to 1.1–4.5°C in rabi by 2070. Similarly, mean rainfall is projected not to change by 2010, but to increase by up to 10% during kharif and rabi by 2070. At the same time, there is an increased possibility of climate extremes, such as the timing of onset of monsoon, intensities and frequencies of drought and floods.

The rise in the concentration of green houses gases was caused primarily by human and industrial activities. The increased agricultural activities and organic waste management are presumed to be contributing to the building up of both methane and nitrous oxide in the atmosphere. However, agriculture in general and Indian agriculture in particular is not contributing significantly to global climatic change, as GHG emissions from agriculture indicate. India's total contribution to global methane emission from all sources is only 18.5 Tg per year. Agriculture (largely rice paddies and ruminant animal production) is a major source of CH_4 emission and contributes 68% to it. The continuously flooded rice fields emit methane, because anoxic conditions favor methanogenesis. Since India and China are the major rice producing countries, US-EPA attributed 37.8 Tg Methane/year to the Indian rice paddies. Based on this estimate, an international opinion was made that Asia and in particular, India and China are contributing significantly to global warming and they should do something to prevent this phenomenon. Sinha et al. (1998) estimated that global annual methane emission from rice cultivation is less than 13 Tg. IPCC (1996) has now revised the estimates of global methane emission from rice to 60 Tg/year. These estimates are still very high and can be further brought down. The contribution of Indian paddies to global CH_4 budget was estimated to be only 4.2 Tg/year (Bhattacharya and Mitra 1998). The main reasons of low methane emissions from rice fields in India are that the soils of major rice growing areas have very low organic carbon are also and not continuously flooded.

Atmospheric concentration of N_2O is increasing at a rate of $0.22\pm0.02\%$ per year (Machida et al. 1995; Battle et al. 1996; Mosier et al. 1998). The emission of N_2O is of serious concern, because of its long atmospheric lifetime of 166 ± 16 years (Prinn et al. 1990). But despite its lower concentration and less rapid rise, N_2O is becoming an important GHG, because of its longer lifetime and greater global warming potential than CO_2 (300 times more than that of CO_2 molecule). About 5% of total greenhouse effect can be ascribed to N_2O and it is also responsible for the destruction of stratospheric ozone (Rodhe 1990). Estimates of total nitrous oxides from Indian agriculture are very low due to low soil fertility and lower amounts of fertilizers used in agriculture as compared to the western countries. In India, CO_2 fixation becomes more important, because we use almost 190 million hectare of land for farming. The estimated dry biomass production from agriculture in India is almost 800 million tons every year. This is equivalent to the fixation of 320 Tg of C or 1000 Tg of CO_2 per annum. Only a part is retained over time due to low body weight of human beings and other consumers and the rest is released to the atmosphere.

2.3 The Impact of Climate Change and Climatic Variability on Agriculture Productivity

2.3.1 Crop Productivity

Increase in atmospheric carbon dioxide has a fertilization effect on crops with C_3 photosynthetic pathway and thus, promotes their growth and productivity. On the other hand, an increase in temperature, depending upon the current ambient temperature, can reduce crop duration, increase crop respiration, alter photosynthate partitioning to economic products, effect the survival and distributions of pest populations thus developing new equilibrium between crops and pests, hasten nutrient mineralisation in soils, decrease fertilizer use efficiency, and increase evapotranspiration. Indirectly, there may be considerable effects on land use pattern due to availability of irrigation water, frequency and intensity of inter- and intra-seasonal droughts and floods, and availability of energy. All of these can have tremendous impact on agricultural production and hence, food security of any region.

Wheat growth simulator (WTGROWS), developed at IARI, New Delhi, has been extensively tested for different agro-environments (Aggarwal and Kalra 1994). In past, it has been successfully used for the resource management, forecasting of wheat yields and climate variability related studies. Using WTGROWS, a strong linear decline in wheat yield was noticed with the increase in January temperature. For every degree increase in mean temperature, grain yield decreased by 428 kg/ha. Inter-seasonal climatic variability analysis carried out through yield response of wheat indicated that impact of the variability was lowest for Kota and highest for Solapur. Inter-seasonal climatic variability has been characterized through growth and yield response under different production environments, which clearly indicate the use of crop model as an indicator of climatic variability/change.

The change in rice yields at improved level of management with change in temperature and CO_2 is plotted in Fig. 2.1. Increase of 1°C temperature without any increase in CO_2 resulted in 5, 8, 5 and 7% decrease in grain yield in north, west, east and southern regions, respectively. Increase of 2°C temperature resulted in 10–16% reduction in yield in different regions, while a 4°C rise led to 21–30% reduction. Sinha and Swaminathan (1991) reported that a 2°C increase in mean air

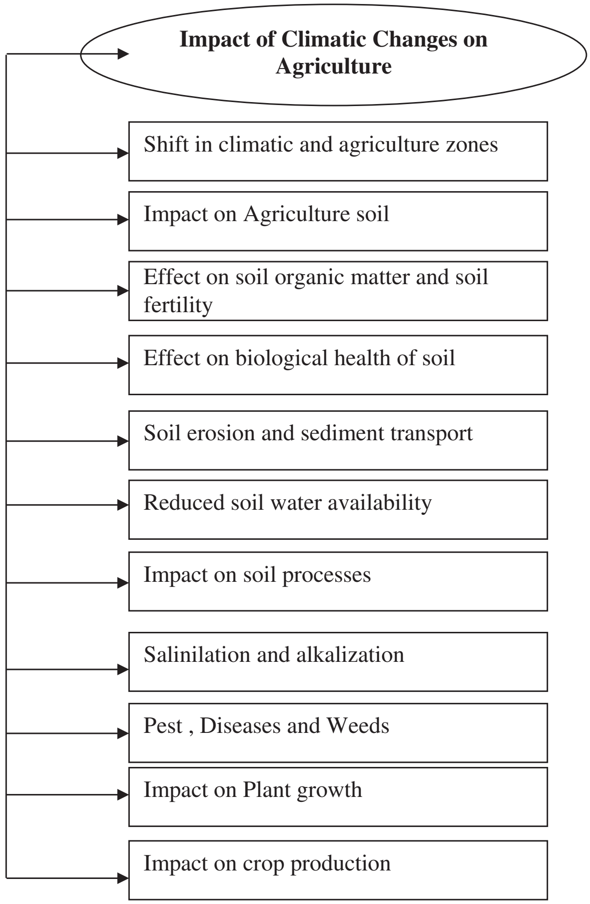

Fig. 2.1 Points that must be considered while doing the study of impacts of climatic changes on agriculture

temperature could decrease rice yield by about 0.75 t/ha in the high yield areas and by about 0.06 t/ha in the low yield coastal regions. Further, a 0.5°C increase in winter temperature would reduce wheat crop duration by seven days and reduce yield by 0.45 t/ha. An increase in winter temperature of 0.5°C would thereby translate into a 10% reduction in wheat production in the high yield states of Punjab, Haryana and Uttar Pradesh. The reduction was lower in eastern India compared to all other regions (Fig. 2.1). Mean grain yields of control crops in eastern region were 7.9 t/ha as compared to 8.7–9.9 t/ha in other regions. This was because of relatively higher temperatures in east (32.2/25.3°C) both during grain formation and filling phase, accompanied by lower radiation. As a result, these crops had fewer grains and shorter grain filling duration. Although temperatures were high in northern India as well (33.8/25.0°C), the region also had more radiation, which resulted in higher grain yields.

The impact of interactions between carbon dioxide and temperature can also be seen in Fig. 2.2. At 350 ppm in north India, there was a change of −5, −12, −21,

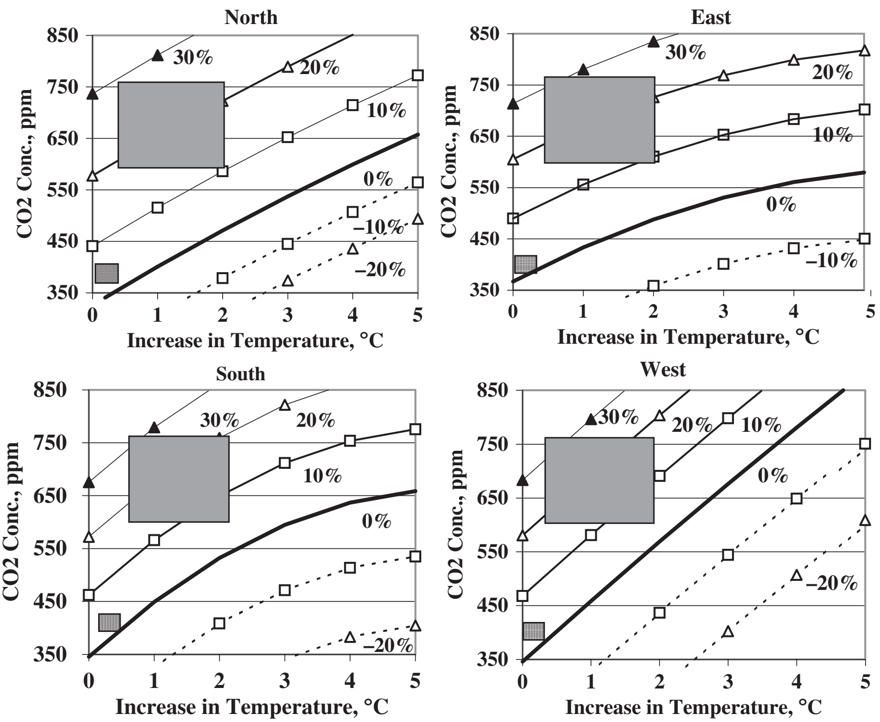

Fig. 2.2 Effect of increase in temperature and CO_2 on simulated grain yields of irrigated rice with improved N management (allowing no N stress) in different regions of India. Lines refer to the equal change in grain yield (% change, labeled) at different values of CO_2 and increase in temperature. Large, shaded box refers to bias in impact assessment due to uncertainties in IPCC scenario of 2070 and the small, hatched box refers to the bias due to uncertainties in the scenario of 2010

−25 and −31% in grain yield with increase of 1, 2, 3, 4, 5°C temperatures, respectively. In the same region, and at the same temperatures but at 550 ppm, these yield changes were 12, 7, 1, −5 and −11%, respectively. Similar interaction could be noted for other regions as well. Thus, in eastern and northern regions, the beneficial effect of 450, 550 and 650 ppm CO_2 was nullified by an increase of 1.2–1.7, 3.2–3.5 and 4.8–5.0°C, respectively (Table 2.1). In southern and western regions, positive CO_2 effects were nullified at temperatures lower than these. It can be concluded that in improved management conditions, the regions, such as southern and western parts of India, which currently have relatively lower temperatures, are likely to show less increase in rice yields under climate change compared to northern and eastern regions.

The effect of sowing at different dates on the yield of wheat was simulated for different locations. Areas having higher potential yields of wheat had greater reduction in yield per day delay in sowing from the optimal date. A few locations (north eastern parts) showed a small yield reduction with delayed sowing. With the temperature rise, the adjustments in the date of sowing to have the similar weather conditions can be ensured, but it can imbalance the cropping system schedule, which is also important for developing countries where intensive cultivation is practiced on small and marginal lands.

Aggarwal and Kalra (1994), by using WTGROWS, demonstrated the shift of iso-yield lines of wheat in India with 425 ppm of CO_2 concentration and 2°C rise in temperature. The rise in carbon dioxide concentration of the atmosphere effectively influences the productivity of crop plants. For these studies, open top chamber facilities have been developed at various Institutes in India. In these chambers, the coupled weather and canopy environment also change along with CO_2, and thus the differences in growth and yield of crops become complex function of these parameters. To work out the impact of carbon dioxide and temperature only, Free Air Carbon Dioxide Enrichment (FACE) facilities have been established at the Indian Agricultural Research Institute, New Delhi in collaboration with National Physical

Table 2.1 Temperature increases (°C) that will cancel out the positive effect of CO_2 in different regions at two levels of management

	CO_2 concentration		
Management	450 ppm	550 ppm	650 ppm
North India			
Improved	1.7	3.2	>5.0
Current	1.9	2.7	4.8
East India			
Improved	1.2	3.5	>5.0
Current	2.0	4.4	>5.0
West India			
Improved	0.9	1.8	2.8
Current	1.0	2.1	3.4
South India			
Improved	1.0	2.3	4.4
Current	0.9	2.0	3.4

Laboratory. Some of the research findings with these facilities are indicated in this section. Enhanced carbon dioxide concentration effects the carbon dioxide assimilation and their partitioning within the source leaf and transport to the sink in mungbean and wheat. Carbon dioxide elevation partially compensates for the negative effect of moisture stress in *Brassica* plants and may possibly help to grow in the drier habitat than they are currently grown. *Brassica* spp. responded differently to elevated carbon dioxide levels. All the yield components in rice viz. panicle number (effective tillers), filled grains per panicle and grain weight responded positively to enhanced carbon dioxide levels. Increased photo-assimilate supply possibly increased the maturity percentage of the seeds. The studies with rice, wheat and mustard are currently being used to refine the existing crop growth models. Presently, the FACE facility has been used to study crop response to CO_2 on growth and yield. The efforts are being made to include also the rising temperature effects (Uprety 1998). This kind of study needs to be also extended to some of the traditional crops of the country, like chickpea, pigeonpea, groundnut and potato.

Gadgil (1995) and Gadgil et al. (1999a, b) used PNUTGRO model to determine the sowing window for rainfed groundnut. Variation in the model yield with sowing date showed that broad sowing window of 22nd June–17th August is the optimum for minimizing the risk of failure. It was also shown that incidence of locally triggered pests/diseases viz. *leaf miner* and late leaf spot (t*ikka*) is low when sowing is postponed to after mid-July and thus does not involve much risk. It was also seen that pod filling stage was critical for moisture availability.

Lal et al. (1999) projected 50% increased yield for soybean for a doubling of CO_2 in Central India. However, a 3°C rise in surface air temperature almost cancels out the positive effects of doubling of carbon dioxide concentration. A decline in daily rainfall amount by 10% restricts the grain yield to about 32%.

Hundal and Kaur (1996) examined the climate change impact on productivity of wheat, rice, maize and groundnut crop in Punjab. If all other climate variables were to remain constant, temperature increase of 1, 2 and 3°C from present day condition, would reduce the grain yield of wheat by 8.1, 18.7 and 25.7%, rice by 5.4, 7.4 and 25.1%, maize by 10.4, 14.6 and 21.4% and seed yield in groundnut by 8.7, 23.2 and 36.2%, respectively.

Lal et al. (1998) examined the vulnerability of wheat and rice crops in northwest India to climate change through sensitivity experiments with CERES model and found that under elevated CO_2 levels, yields of rice and wheat increased significantly (15 and 28% for a doubling of CO_2). However, a 3°C (2°C) rise in temperature cancelled out the positive effect of elevated CO_2 on wheat (rice). The combined effect of enhanced CO_2 and imposed thermal stress on the wheat (rice) crop is 21% (4%) increase in yield for the irrigation schedule presently practiced in the region. While the adverse impact of likely water shortage on wheat crops would be minimized to a certain extent under elevated CO_2 levels, it would largely be maintained for the rice crops resulting in net decline in the rice yields.

Mandal (1998), Chatterjee (1998) and Sahoo (1999) calibrated and validated the CERES-maize, CERES-sorghum and WOFOST models for the Indian environment and subsequently used them to study the impact of climate change (CO_2 levels: 350

and 700 ppm and temperature rise from 1 to 4°C with 1°C increment) on phenology, growth and yield of different cultivars. Chatterjee (1998) observed that an increase in temperature consistently decreased maize and sorghum yields from the present day conditions. Increase in temperature by 1 and 2°C, the sorghum potential yields decreased by 7–12%, on an average. An increase in 50 ppm CO_2 increases yields by only 0.5%. The beneficial effect of 700 ppm CO_2 was nullified by an increase of only 0.9°C in temperature.

However, Mandal (1998) observed that an increase in temperature up to 2°C did not influence potential and irrigated yields of chickpea as well as above ground biomass significantly. Pre-anthesis and total crop duration got reduced with the temperature rise. Nitrogen uptake and total water use (as evapo-transpiration) were not significantly different upto 2°C rise. The elevated CO_2 increased grain yield under potential, irrigated and rainfed conditions. There was a linear increase in grain yield, as the CO_2 concentration increased from 350 to 700 ppm. Potential grain yield of pigeonpea decreased over the control when the temperature was increased by 1°C (using WOFOST).

Sahoo (1999) carried out simulation studies of maize for climate change under irrigated and rainfed conditions. Rise in temperature decreased the yield under both the conditions. At CO_2 level of 350 ppm, grain yield decreased continuously with temperature rise till 4°C. This was possibly due to reduction in days to 50% silking and physiological maturity. At CO_2 level of 700 ppm, grain yield increased by about 9%. The temperature rise effect in reduction of yield was noted in several maize cultivars. Effect of elevated carbon dioxide concentration on growth and yield of maize was established, but less pronounced when compared with crops, like wheat, chickpea and mustard crops. The beneficial effect of 700 ppm CO_2 was nullified by an increase of only 0.6°C in temperature. Further increase in temperature always resulted in lower yields than control.

The sensitivity experiments of the CERES-rice model to CO_2 concentration changes, as conducted by (Saseendran et al. 1999), indicated that over the Kerala State, an increase in CO_2 concentration led to yield increase due to its fertilization effect and also enhanced the water use efficiency. The temperature sensitivity experiments have shown that for a positive change in temperature up to 5°C, there is a continuous decline in the yield. For every one degree increment, the decline in the yield is about 6%. Also, in another experiment, it was noticed that the physiological effect of ambient CO_2 at 2°C in temperature was compensated for the yield losses at 425 ppm CO_2 concentration.

Estimates of impact of climate change on crop production could be biased depending upon the uncertainties in climate change scenarios, region of study, crop models used for impact assessment and the level of management. Aggarwal and Mall (2002) studied the impact of climate change on grain yields of irrigated rice with two popular crop simulation models – Ceres-Rice and ORYZA1N at different levels of N management. The climate change scenarios used were 0.1°C increase in temperature and 416 ppm CO_2 (2010 scenario) and 0.4°C temperature and 755 CO_2 (2070 scenario) as the optimistic scenario, whereas increase of 0.3°C temperature and 397 ppm CO_2 (2010 scenario) and 2.0°C temperature and 605 ppm CO_2 (2070 scenario) as the pessimistic scenarios of climate change, as adopted from studies of Watson et al. (1998). The results showed that the direct effect of climate change on rice crops in different agro-climatic regions in India would always be positive irrespective of the various uncertainties. Depending upon the scenario, rice yields increased between 1.0 and 16.8% in pessimistic scenarios of climate change depending upon the level of management and model used. These increases were between 3.5 and 33.8% in optimistic scenarios. These conclusions are highly dependent on the specific thresholds of phenology and photosynthesis to change in temperature used in the models. Caution is needed in using the impact assessment results made with the average simulated grain yields and mean changes in climatic parameters.

Screening of cultivars for tolerance to sterility under enhanced temperatures during post anthesis phase for the major crops needs to be evaluated in the phytotron (control chambers), for choosing the appropriate cultivars for sustained productivity under climate change. Quality aspects for important crops, like wheat (aestivum and durum), basmati rice and mustard under the climate change, need to be addressed. There is also a need to develop a selection criterion for screening of the cultivars for adaptation to drought and temperature stresses.

Adaptation of crops to gradual change in the climatic conditions needs to be included in the existing crop growth models, as it is not well understood. Moreover, the suitable agronomic and resource management options may nullify the ill effects of climate change on growth and yield of crops.

2.3.2 Soil Productivity

The most important process is the accelerated decomposition of organic matter, which releases the nutrients in short run, but may reduce the fertility in the long run. Soil temperature influences the rates at which organic matter decomposes, nutrients are released and taken up, and plant metabolic processes proceed. Chemical reactions, that affect soil minerals and organic matter, are strongly influenced by higher soil and water temperature. Soil productivity and nutrient cycling are, therefore, influenced by the amount and activity of soil microorganisms. Soil microorganisms fulfill two major functions, i.e. they act as agents of nutrient element transportation as well as store carbon and mineral nutrients (mainly N, P and S) in their own living biomass, acting as a liable reservoir for plant available nutrients with a fast turnover. The doubling of CO_2 increases plant biomass production, soil water use efficiency by the plants, and C/N ratios of plants. The changes in the C/N ratios of plant residues returned to the soil, have impact on soil microbial processes and affect the production of trace gases NOx and N_2O.

Results of the All India Co-ordinated Long-term Fertility Trials indicate that regions, having higher organic carbon content (>0.6%) in the beginning, showed a declining trend, whereas the regions with lower organic carbon content remained more or less static or slight increase in the organic carbon content was noticed in around 25 years. In general, Indian agricultural soils are low in organic carbon content, and for achieving higher agricultural production, we have to depend upon the fertilizers. The hypothesis of increased organic carbon degradation with temperature rise has to be linked with the crop intensity factor, which is significantly higher for India, where proportion of the small and marginal land holdings is increasing due to rapid growth in population with time.

The interaction of nitrogen, irrigation and seasonal climatic variability, particularly at low input of irrigation, has several implications. Under adequate moisture supply situation, like for Punjab and Haryana, the yield benefits are obtained up to higher nitrogen application, whereas in the regions of limited to moderate water supply situations, the increasing trends in yield are noted up to relatively lower values of nitrogen. At low levels of water availability, it is difficult to decide optimal levels of N fertilizer for maximizing yield returns in view of uncertainty of N response, which is strongly related to a good post monsoon rainfall received during crop growing period (Kalra and Aggarwal 1996).

Das and Kalra (1995) evaluated the fertilizer and resource management for enhancing crop productivity under inter-annual variations in weather conditions. The results revealed sensitivity of crop yields to climatic variability and the need of inputs management in relation to climatic variability. Simulation models for judging the soil nutrient availability and subsequently relating to growth and yield of crops are available, but needs to be refined and thoroughly tested for the climate change event.

Analysis of the food grains production data for the last few decades reveals a tremendous increase in yield due to technological advancement, but it appears that impact of vagaries of monsoon has been large throughout the period. The annual food production showed an increasing trend, and the deviations around the technology trend line were significantly related to seasonal rainfall. But no definite trend is noticed in case of rabi season food production with the winter season's rainfall, as majority of the food production in this season comes from the irrigated areas.

Changes in rainfall due to global climate change may affect the surface moisture availability, which becomes important for germination and crop stand establishment in the rainfed areas. Modifications in the surface and ground water availabilities with the rainfall change, are difficult to be observed when the land use and land cover are so rapidly changing.

Farmers have several agronomic management options to face the situation of water scarcity, through choice of crops, cultivars, adoption of suitable irrigation, nutrient and pesticides application schedules.

Water production functions, which relate to water availability and its use with crop yields, help in identifying critical growth stages at which the limited amount of water can be applied to get the maximum benefits (Kalra and Aggarwal 1994).

Soils dominate the cycling of many atmospheric trace gases because of the highest abundance and diversity of microbes in them. Earlier, equilibrium used to exist between the sources and sinks of GHGs, but a shift in this equilibrium has started becoming evident as a consequence of human induced activities. In order to comprehend the shift of source – sink equilibrium, one needs to understand the processes involved in generating the net flux (a function of production processes, consumption processes and gas transport) at the soil atmosphere interface.

Microbes have emerged as the major contributor as well as consumer of GHGs as they are the main intermediaries of C turnover in soil. They are also considered as sole agents for soil humus formation, cycling of nutrients, soil tilth and structure and also perform myriad of other functions. What will happen to the soil fertility in the event of global climate change needs to be addressed through soil organic matter (SOM)? The assessment of soil health/quality/fertility through changes in SOM is difficult, and therefore, other soil parameters are being used as proxy indicators. For example, soil microbial biomass (the living part of organic matter) due to dynamic character has been shown to quickly respond to changes and perturbations, often before the measurable changes occur in organic C and N, thus acting as an indicator of long term changes in SOM content (Powlson and Brookes 1987). However, the measurement of microbial biomass (C_{mic}) alone will not serve the purpose, because they are generally influenced by climatic variables. Hence, for real measurement of the impact of soil processes, one needs to consider proportion of total organic C or N within the microbial biomass i.e. microbial quotient. Under the equilibrium conditions, C_{org} of agricultural soils contains 2.3–4% C_{mic}. Soils exhibiting a C_{mic} to C_{org} ratio higher or lower than these values appearing in the equilibrium line would be either accumulating or losing C, respectively (Anderson and Domsch 1986). Different climatic conditions, in particular precipitation/evaporation, influence the equilibrium C_{mic} to C_{org} ratio (Insam 1990) and a very high correlation was found in which 73% variation could be explained with the quadratic function, and thereby one can predict the soil fertility in terms of accumulation or losses of C.

Under the changed scenario of atmospheric composition due to global warming, the tropical region, such as India, with small organic C reserves, will show net efflux of CO_2, because rates of soil respiration increase exponentially with temperature. Thus, CO_2 effluxes from tropical system should increase markedly with small change in temperature without any increase in inputs from the above ground communities, thereby leading to rapid losses over a short period of a few decades and later on, it will sustain the balance because of the shortage of substrate for decomposition as well as adaptation of microbial communities towards the climatic change. The alterations in microbial community structure and their physiology can be interpreted in terms of differences in phospho-lipid fatty acids (PLFA) – fingerprinting. In general, PLFA profiles had decreasing unsaturation, greater chain length and larger number of cyclopropyl fatty acids at higher temperatures.

It has also been suggested that climate change could increase rates of soil erosion, further hampering food production. Increases in rainfall will accelerate the rates of soil loss, reducing farm productivity even more. A further negative consequence of accelerated erosion will be increased sedimentation in streams and reservoirs. This will shorten the life span of dams, which helps to prevent floods and provide both electricity and water for irrigation. Another way, in which erosion could accelerate, is through a decrease in rainfall, which could lead to dry spells and increased risk of wind erosion (Parry et al. 1999). If erosion rates go unchecked, continued soil impoverishment would eventually force farmers to abandon their lands. Thus, erosion is among the major threats to food production in a warmer climate. But, these qualitative assessments have not been studied in depth, where the rapid changes in land use patterns may totally reverse our thinking.

Other land degradation problems, such as water logging, soil salinity and sodicity development, are emerging due to rapid land use pattern and land cover changes. The impact of climate change on these aspects needs to be looked into for sustaining the agricultural production.

2.3.3 Insects and Pests

Incidence of pest and diseases is most severe in tropical regions due to favorable climate/weather conditions, multiple cropping and availability of alternate pests throughout the year. Therefore, in the south Asia, pests and diseases deleteriously affecting the crop yields are prevalent. Climatetors are the causative agents in determining the population fluctuations of pests. They influence plant disease establishment, progression and severity. In fact, a clear understanding of population dynamics, as influenced by abiotic and biotic parameters of environment, is of much help in pest forecasting and to formulate control measures.

Indicators of climate change can be a few of the crop species, rhythm/migratory behavior of specific insects/birds, etc. The global warming may affect growth and development of all organisms including insect-pests themselves. Among all the abiotic factors, temperature is the most important one affecting insect distribution and abundance in time and space, since these are cold-blooded animals. The insects cannot regulate their body temperature and thereby, ambient temperature influences their survival, growth, development and reproduction.

The swarms of locust produced in the Middle East usually fly eastward into Pakistan and India during summer season and they lay eggs during monsoon period. The swarms as a result of this breeding, return during autumn to the area of winter rainfall, flying to all parts of India and influencing *kharif* crops (Rao and Rao 1996). Changes in rainfall, temperature and wind speed may influence the migratory behaviour of locust.

Diseases are often hurdles in increasing rice productivity. The rice blast, caused by *Pyricularia grisea*, is most prominent disease across the eco-systems. In the past, rice blast, brown spot and stem rot, were the serious diseases. Consequent to the adoption of high yielding varieties and associated agronomic practices during 1970's, diseases like bacterial leaf blight, sheath blight, sheath rot, tungro virus (transmitted by *Nephotettix* spp.) and bacterial leaf streak, have gained importance over the traditionally known diseases, especially stem rot and brown spot. False smut and discolouration of rice grain, caused by several fungi, have been of minor significance with occasional concern in certain regions only. While analyzing the effect of climatic variability and change on disease status, the interaction of land use and land cover change should also be taken into consideration.

Climate and weather selectively induce specific diseases to develop. The monocyclic diseases, such as stem rot, sheath rot and false smut, are less influenced by the ambient weather conditions. Epidemics of monocyclic diseases are relatively rare in the sense of an explosive increase in their population. In contrast, the polycyclic diseases, such as blast, brown spot, bacterial leaf blight and rice tungro virus that invade the aerial parts of the plants, are subjected to constant interaction with weather. They easily attain epidemic proportions to cause heavy losses (Abrol and Gadgil 1999).

Forecasting of aphids (*Lipaphis erysine* Kalt) on mustard crop, grown during winter season in northern part of India based on the movement of western disturbances, has been established (Ramana Rao et al. 1994). Western disturbances bring in cold and humid air from the Mediterranean region, resulting in cloudy and favourable weather conditions for occurrence of aphids on mustard crop. It was observed that there was a sharp increase in the population of aphids when the mean daily temperature ranged from 10 to 14°C, with relative humidity of 67–85% and cloudiness greater than 5 octas.

For every insect species, there is a range of temperature within which it remains active from egg to adult stage. Lower value of this range is called threshold of development or developmental zero. Within favourable range, there is an optimum temperature where most of the individuals of a species complete their development. Exposure to temperature on either side exerts an adverse impact on the insect by slowing down the speed of development (Pradhan 1946).

The studies have shown that insects remain active within temperature range from 15 to 32°C (Phadke and Ghai 1994). In case of red cotton bug, at constant temperature of 20, 25 and 30°C, the average duration of life cycle was found to be 61.3, 38.3 and 37.6 days, respectively, while at 12.5 and 35°C, the pest did not show any development (Bhatia and Kaul 1966).

A maximum temperature ranging from 19 to 24°C with a mean of 12–15°C for mustard aphid, *Lipaphis erysimi*; maximum temperature between 26.9 and 28.2°C with a relative humidity of 80.6–82.1% for rice stink bug; temperature from 20 to 28°C for rice green leafhopper, temperature from 24.8 to 28.6°C for brown plant hopper; mean temperature around 27.5–28.5°C for aphids, thrips and leaf weevil on green gram and maximum temperature from 23 to 27.8°C for gram pod borer, have been found most congenial for their development (Phadke and Ghai 1994).

With the increase in temperature, the rate of development of insects may also increase, if temperature still lies within the optimal range for the pests. As a consequence, they could complete more number of generations for inflicting more loss to our crops. Crop-pest interaction needs to be evaluated in relation to climate change in order to assess the crop losses.

Development of diseases and pests is strongly dependent upon the temperature and humidity. Any change in them, depending upon their base value, they can significantly alter the scenario, which ultimately may result in yield loss. Any small change in temperature can result in changed virulence as well as appearance of new pests in a region. Likewise, crop-weed competition may be affected, depending upon their growth behaviour.

The following scenarios can be visualized regarding impact of climate change on pest dynamics in agriculture.

- With an increase in concentration of carbon dioxide, the nutritional status of crop will change, and the net effect on agricultural production will depend upon interaction between pests and crops.
- Gradual climate warming will lead to changes in the composition of pest fauna in different areas. The high population growth rate of many species will ensure changes in pest distribution.
- If the rise in winter temperature takes place, the duration of hibernation of pests may decrease, thus increasing their activity.
- Uncongenial areas for pests due to low temperature at present may become suitable due to rise in temperature.

However, we should not forget that insects could adapt to slow changes in the environment and with increase in temperature, their favorable range of temperature may also shift.

2.4 Socio-Economic Aspects

Socio-economic linkage is relatively complex, and needs to be linked through the bio-physical modifications associated with the climate change. Land use and land cover change in our country is changing rapidly due to several driving forces. Socio-economic aspects can be dealt in two ways, one working out the cost-benefit analysis for various climate change scenarios by using econometric-process models (Antle and Capalbo 2001) and the other, generating the socio-economic scenario of future which links with the cropping system model for further impact analysis.

World Bank report (1998) analyzed climate change effects on Indian agriculture, through annual net revenues, by using Ricardian method (Mendelsohn et al. 1994). The three methodologies, as adopted in the study, found Indian Agriculture sensitive to warming. The analyses further showed year-to-year climate sensitivity to the system's response. The studies revealed that net revenues fall precipitously with warmer April's, but also sensitive to warmer January and July. Crop revenues increased with October temperatures. Net revenues were also sensitive to precipitation, but the effects were smaller and off-setting. A warming scenario of $+2.0^{\circ}C$ rises in mean temperature and a $+7\%$ increase in mean precipitation levels will create reduction in the net revenues, as revealed from the three approaches. The impact is differential on spatial and temporal scales. But the study seemed to be weak for linking with the biophysical aspects. Even then, this kind of study is a beginning of future plans of initiating the work in this regard.

2.5 Mitigation Options of Green House Gases Emission

The possible strategies for mitigating methane emission from rice cultivation can be made by altering water management, particularly promoting mid-season aeration by short-term drainage. Improving organic matter management by promoting aerobic degradation through composting or incorporating into soil during off-season drained period, is another promising technique. Organic amendments to flooded soils increase methane production and emission. However, application of fermented manure, like biogas slurry, reduces the emission (Debnath et al. 1996). In addition, nitrification inhibitors have been shown to inhibit methane emission. Another mitigation option may be selection of low CH_4 emitting rice cultivars, as cultivars grown in similar conditions show pronounced variations in methane emission (Mitra 2000). Screening of rice cultivars with few unproductive tillers, small root system, high root oxidative activity and high harvest index are ideal for mitigating methane emission from rice fields.

Combined with a package of technologies, methane emission can best be reduced by (a) the practice of mid-season drainage instead of continuous flooding, (b) direct crop establishment like dry seeded rice and (c) use of low C: N organic manure and biogas slurry.

Appropriate crop management practices, which lead to increase N use efficiency and yield, hold the key to reduce nitrous oxide emission. Application of nitrate (NO_3–N) fertilizers e.g. calcium ammonium nitrate (CAN), in crops with aerobic conditions and ammonium (NH_4–N) fertilizers e.g., ammonium sulphate, urea, in wetland crops also help reducing the nitrous oxide emission (Pathak and Nedwell 2001). Curtailing the nitrification process by the use of nitrification inhibitor may further decrease the N_2O emission from soil. There are some plant-derived organics, such as neem oil and neem cake, which can also act as nitrification inhibitors. These are being experimented in fields to reduce the emission of nitrous oxide and increase the fertilizer use efficiency. Other biocidal inhibitors, such as karanja seed extract, have been found to retard nitrification by 60–70% (Majumdar et al. 2000). The efficacy of various mitigation technologies, however, needs to be tested in farmers' fields. Moreover, such technologies need to be also assessed for non-target effects and economic feasibility.

2.6 Vulnerability and Adaptation Strategies

There must be a clear understanding of vulnerable populations and regions, based on an assessment of the capacities to cope with climate variability and change. We are conscious that coping and adaptation strategies are not equally available to all affected populations. At the same time, it is important also to develop formal measures of vulnerability and their application to planning adaptation measures and strategies. The inter-disciplinary work involved requires various Ministries, Agencies and Expert Institutions to pool their resources, knowledge and information. We need to know much more about the factors influencing vulnerability and the aspects related to planning for adaptation. Our understanding in the area of vulnerability and adaptation tools needs to be mature and be refined so as to enhance their applicability.

India is particularly vulnerable to likely increase in the incidence of extreme events. The impacts of climate change could hinder development and progress in eradicating poverty and potentially aggravating social and environmental conditions. In the context of the current debate about climate change, it is necessary to show that the developing countries, like India, are taking considerable actions in terms of policies, programmes and projects. Technology transfer can speed up the modernization process and additional funds can accelerate government initiatives in energy conservation. However, policies for poverty alleviation must be on high priority.

The hierarchy of damage considerations as discussed above – hunger, regional economic, farmer/farm sector, and yield vulnerability, helps to focus on adaptive strategies that reduce vulnerability. How can we avoid yield failures? If yields fail, what other crops can be grown? If farming becomes uneconomic, what can be alternate land use options to increase the profits to the farmers?

Historically, farming systems have adapted to changing economic conditions, technology and resource availabilities and have kept pace with a growing population. While the technological potential to adapt may exist, the socio-economic capability to adapt differs for different types of agricultural systems. An evergreen revolution is the pathway to sustainable advances in productivity per units of land, water and time without associated ecological or social harm. One of the weaknesses is mismatch between production and post-harvest technologies and between production and market demand, and the consequent need for the Government of India to undertake "trade relief" operations like cyclone, flood and drought relief. We can face the internal threats through integrated attention to regulation, education and social mobilization through Panchayati Raj institutions. Also, there is a need to restructure research strategies in a manner that strategic, anticipatory and participatory (i.e. with farm families) research, all receive adequate attention.

The Rural Knowledge Centers should provide computer aided and internet connected information services, so that farm families have timely and relevant meteorological, management and marketing information. Another area, which needs an urgent attention, is the restructuring of the State Land Use Boards in a manner that they are in a position to offer proactive advice to farm families on land use and cropping systems, based on likely monsoon behaviour, ecological efficiency and trends in prices and markets. Assured and remunerative marketing opportunities hold the key to sustaining farmers' interest in producing more.

Immediately, an action is needed to defend the productivity gains we have already made and to extend the same to the areas which have been bypassed by the farm revolution, particularly dry farming areas, and to make new gains through sustainable intensification, market – based farming systems diversification, and value addition to primary produce through agro-processing and agri-business.

The income and on-farm and off-farm employment potential of farming can be improved only through integrated farming systems, based on crop-livestock-fish-trees combinations. Multiple livelihood opportunities are essential both as an insurance mechanism and for a reasonable total "take-home" income. India's strength lies in a farming systems approach to the use of natural resources. This is also the pathway to ecological farming. Such research is best done in farmer's fields through a participatory approach. Conservation of bio-resources, particularly medicinal plants and agro biodiversity in dry farming areas, and their conversion into economic products through biotechnology, will help to end the situation where "poor people inhabit a rich country".

2.7 Conclusion

The climate change, as realized through trends of temperature rise and increased CO_2 concentration, is a major concern. In the recent past, the number of studies for assessing its impact on agriculture has increased. Crop growth models have been modified and tested for various important crops of this region under different climate change scenarios. But most of the results happen to be region specific and with certain assumptions. Accuracy in assessing the magnitude of the climate change on higher spatial and temporal resolution scale is the prime requirement for accurate estimates of the impact. The extent of inter- and intra-annual variability in climate happens to be large in this region, and the crops respond differentially to these changes. Understanding of this differential behavior can aid in working out the impact of climate change. The vast genetic diversity in crops provides a platform to identify suitable thermal and drought tolerant cultivars for sustained productivity in the changed climate. Identification of suitable agronomic management practices can be a potential solution to optimize agricultural production in the changed climate. To have an overall assessment of soil health with the climate change, the possible alterations in soil physical, chemical and biological characters need to be looked into by also including land use and land cover change driving forces. Intensive cultivation in our country has already started showing signs of yield stagnation in some parts of north-west India, raising the alarm of sustaining the yields by adoption of suitable agronomic management options. This concern has now to be viewed along with the climate change and its variability. Increased frequency of droughts and floods in this region, as anticipated in the climate change scenarios, caution us to identify suitable "no regrets and no risks" management options to face the situation. Crop simulation technique offers an opportunity to link the climate change with the other socio-economic and bio-physical aspects. These models can effectively work out the impact and also suggest suitable mitigation options to sustain the agricultural productivity. But one has been cautious in extrapolating the results to a larger region, as most of the exercises are done with certain assumptions, otherwise the results can be misleading. The crop-pest-weather interaction studies, conducted in the past, need to be thoroughly investigated for developing a sub-routine to link with the crop growth models to give the realistic estimates. Socio-economic aspects of climate change are relatively weak, and future scenarios are to be generated for various agro-ecological regions for subsequently linking with other relational layers to work out the impact.

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