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Enhancing Resilience of Indian Agriculture to Climate Change

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Indian agriculture is highly prone to the risks due to climate change caused by increase in the concentration of atmospheric greenhouse gases (GHGs) i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The recent Assessment Report of the Inter-Governmental Panel on Climate Change (IPCC) reiterated that the warming of the climate system is unequivocal and may intensify in coming decades. Climate change can affect agriculture through direct and indirect effects on the crops, soils, livestock and pests. Development of technologies for adaptation and mitigation and their uptake at speedy rate by the farmers are essential for climate change management. Potential adaptation strategies include developing cultivars tolerant to heat and salinity stress and resistant to flood and drought, modifying crop management practices, improving water management, adopting new farm techniques such as resource conserving technologies (RCTs), crop diversification, improving pest management, better weather forecasts and crop insurance and harnessing the indigenous technical knowledge of farmers. There is a need to develop policy framework for implementing the adaptation and mitigation strategies so that the farmers are saved from the adverse impacts of climate change and the food and nutritional security of the country is ensured.

INTRODUCTION

Agriculture is crucial for ensuring food, nutrition and livelihood security of India. It engages almost two-third of the workforce in gainful employment and accounts for a significant share in India's Gross Domestic Product (GDP). Several industries depend on agricultural production for their requirement of raw materials. On account of its close linkages with other economic sectors, agricultural growth has a multiplier effect on the entire economy of the country. Although in recent years, Indian agriculture has made a significant progress, currently it is facing many challenges too. Stagnating net sown area, plateauing yield levels, deterioration of soil and quality, reduction in per capita land availability and the adverse effects of climate change are the major challenges for Indian agriculture. On the other hand, the increased rate of population is pressurizing the agricultural sector for enhanced food production. The task is very challenging because about 60% of the net cultivated area is rainfed and exposed to stresses arising from climatic variability and climate change. More than 80% of Indian farmers are marginal and small with poor coping capacity. Furthermore, the Indian farms are diverse, heterogeneous and unorganized. Climatic change and variability are likely to aggravate the problem of future food security by putting pressure on agriculture affecting its sustainability.

Change in the global climate scenario results in warming of atmosphere and ocean, melting and/or diminishing glaciers, rise in sea level and increase in the concentrations of greenhouse gases. However, the most prominent environmental issue due to climate change is the global warming, caused by increase in the concentration of atmospheric greenhouse gases (GHGs) i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These GHGs trap the outgoing infrared radiation from the earth's surface and thus raise the atmospheric temperature. Recent observations show increase in temperatures, hot days, hot nights and heat waves; increasing frequency of heavy precipitation events; increased snow melt and rise in sea level. The Inter-Governmental Panel on Climate Change (IPCC), in its Fifth Assessment Report reiterated that the warming of the climate system is unequivocal. Anthropogenic influence on the climate system is evident from the increasing greenhouse gas concentrations in the atmosphere and positive radiative forcing. Global climate change has considerable impacts on the crops, soils, livestock and pests. The paper discusses the impacts of climate change on Indian agriculture and the strategies and technologies for climate resilient agriculture.

Impacts of Climate Change on Indian Agriculture

Indian agriculture is highly prone to the risks due to climate change; especially to drought, because 2/3rd of the agricultural land in India is rainfed and even the irrigated system is dependent on monsoon. Flood is also a major problem in many parts of the country, especially in eastern part, where frequent flood events take place. In addition, frost in north-west, heat waves in central and northern parts and cyclone in eastern coast also cause havoc. In recent years, the frequency of these climatic extremes are getting more due to the increased atmospheric temperature, resulting in increased risks with substantial loss of agricultural production.

Climate change can affect agriculture through direct and indirect effects on the crops, soils, livestock and pests. Increase in atmospheric carbon dioxide has a fertilization effect on crops with C_3 photosynthetic pathway and thus promotes their growth and productivity. Increase in temperature can reduce crop duration, increase crop respiration rates, alter photosynthesis process, affect the survival and distributions of pest populations and thus developing new equilibrium between crops and pests, hastens nutrient mineralization in soils, decrease fertiliser use efficiencies, and increase evapo-transpiration. Climate change also have considerable indirect effects on agricultural land use in India due to availability of irrigation water, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, changes in pest profiles, decline in arable areas due to submergence of coastal lands and availability of energy. The probable impacts of climate change on various sectors of Indian agriculture are:

Crop

♦ Increase in ambient CO_2 is beneficial since this leads to increased photosynthesis in several crops, especially crops with C_3 mechanism of photosynthesis such as Wheat and Rice, and decreased evaporative losses. Despite this, the yields of major cereals crops especially like Wheat is likely to be reduced due to decrease in crop growth duration, increased respiration, and /or reduction in rainfall/ irrigation water supplies due to rise in atmospheric temperature.

♦ Enhanced frequency and duration of extreme weather events such as flood, drought, cyclone and heat wave; that adversely affect agricultural productivity.

♦ Reduction in yield in the rainfed areas due to increased crop water demand and changes in rainfall pattern during monsoon.

♦ Declined quality of fruits, vegetables, tea, coffee, aromatic, and medicinal plants.

♦ Alteration of agricultural pests and diseases because of more pathogen and vector development, rapid pathogen transmission and increased host susceptibility.

♦ Threatened agricultural biodiversity by rainfall uncertainty and temperature increase, sea level rise, and increased frequency and severity of drought, cyclones and floods.

♦ Contrary to all the above negative impacts, predictions have been made for decreased cold waves and frost events in future due to the atmospheric temperature rise, which would lead to a decreased probability of yield loss associated with frost damage in northern India in crops such as mustard and vegetables.

Water

♦ Increased irrigation demands with increased temperature and higher evapo-transpiration. This may also result in lowering groundwater table at some places.

♦ Melting of glaciers in the Himalayas may lead to increased water availability in the Ganges, Brahmaputra and their tributaries in the short run but in the long run the availability of water would decrease considerably.

♦ A significant increase in runoff is projected in the wet season that may lead to increase in frequency and duration of floods and also soil erosion. However, the excess water can be harvested for future use by expanding storage infrastructure. The water balance in different parts of India is predicted to be disturbed and the quality of groundwater along the coastal track will be more affected due to intrusion of sea waters.

Soil

♦ Reduced quantity and quality of organic matter content, which is already quite low in Indian soil.

♦ Under elevated CO_2 concentration, crop residues have higher C:N ratio, which may reduce their rate of decomposition and nutrient supply.

♦ Increase of soil temperature will increase N mineralization but its availability may decrease due to increased gaseous losses through processes such as volatilization and denitrification.

♦ Change in rainfall volume and frequency and wind intensity may alter the severity, frequency and extent of soil erosion.

♦ Rise in sea level may lead to salt-water ingression in the coastal lands turning them less suitable for conventional agriculture.

Livestock

♦ Climate change has pronounced effect on feed production and nutrition of livestock. Increased temperature results in enhanced lignification of plant tissues and reduced digestibility. Increased water scarcity would also decrease food and fodder production.

♦ In cooler areas, climate change has major impacts on vector-borne diseases of livestock by the expansion of vector populations. Changes in rainfall pattern may also influence expansion of vectors during wetter years, leading to large outbreaks of disease.

♦ Global warming would increase water, shelter and energy requirement of livestock for meeting projected milk demands.

♦ Climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their reproductive performance.

Fishery

♦ Increasing sea and river water temperature is likely to affect fish breeding, migration and harvests.

♦ Impacts of increased temperature and tropical cyclonic activity would affect the capture, production and marketing costs of the marine fish.

♦ Coral bleaching is likely to increase due to higher sea surface temperature.

During the last decade, Indian agriculture, including crop, livestock, fishery and poultry, had to face several weather extremes due to climate change. Some of the impacts of climate change on Indian agriculture as recently observed in the crop, livestock, fishery and poultry sectors are presented below.

Impacts on Crop

Droughts in 2002, 2004, 2006, 2009, 2010 and 2012; floods in 2005, 2006, 2008, 2010 and 2013; heat waves in May 2003 in Andhra Pradesh; cold waves in 2002-03 and 2005-06 and high temperature during January-March in 2004, 2005, 2010 are some of the recent examples of climatic extremes in India. The drought in 2002 was mainly on account of drastic failure of monsoon in the month of July, when the whole country was 51% deficient of rainfall than the normal. The deficiency in rainfall in north-west India was 62%, peninsular India 36% and north-east India 11%. Because of this drought, 18 million ha (Mha) area was left unsown, crop of 47 Mha was damaged with 29 M ton (Mt) loss in production dipping it to 183 Mt in 2002 against 212 Mt in 2001. Production of Rice fell drastically to 76 Mt from 94 Mt during the previous year. Production of oilseeds also declined by 13.7%. Rabi rice, wheat, coarse cereals, pulses and oilseeds recorded negative growth rates of 31%, 4%, 13%, 10% and 14%; respectively; over the corresponding season in previous year. Cotton and sugarcane also recorded negative growth rates of 7.7% and 7.2%, respectively. Around 150 million cattle were affected due to lack of fodder and water. Decline in the average milk procurement went to the extent of 22% in Rajasthan, 8% in Madhya Pradesh and 7% in Tamil Nadu. The drought affected around 155 million farm dependable households. The total rural employment shrinkage was estimated at 1250 million man-days. The gross domestic product (GDP) in agriculture shrunk by 3.1% during that year. Although the overall impact of drought on GDP was restricted to only 1%, the loss of agricultural income was around Rs 39,000 crores. In addition, cold wave of January 2003 resulted in poor fruiting in mango, papaya, banana, brinjal, tomato and potato, and also in winter Maize and boro Rice. Higher temperatures during March in 2004, in the Indo-Gangetic plains (IGP), caused Wheat crop to mature earlier by 10-20 days resulting in reduction in Wheat production by more than 4 million tonnes in the country (21). Losses were also very significant in other crops, such as mustard, peas, tomatoes, onion, garlic, and other vegetable and fruit crops. Similarly, irregular monsoon in 2009 caused significant reduction in Rice production. Further more, climate change possessed a great influence on Indian horticulture sector too. Apple productivity declined by 40-50% in the areas of Himachal Pradesh where elevation is 1500 m from mean sea level (MSL), partly due to warmer climate resulting in lack of chilling requirement during winter and warmer summers. This is also one of causes for shifting of apple production to higher elevation (2700 m MSL). Cold waves have shown significant impact on crop production in northern India. Cold waves during December 2002 and January 2003 caused considerable damage to horticultural crops such as mango, guava, papaya, brinjal, tomato and potato crops. Occurrence of frost during January 2008 in Rajasthan has affected mustard and cumin resulting in total crop failure. High temperature and moisture stress resulted in sun burn and cracking in apples, apricot, cherries and litchi and also caused dehydration injury to panicles and low fruit set in mango (21). The impact of climate change related events like droughts and heavy rainfall events affected the productivity of plantation crops such as coconut and cashew (5, 15).

Future Climate Projections and its Impact on Crop Productivity

As per IPCC 5th Assessment Report (6), over the mid-term (2046–2065), an increase of 2-4°C is projected for South Asia with daily maximum temperature to increase by 4-7°C and the number of nights above 20°C is projected to significantly increase, with mostly concentrated mainly in India and Thailand. Annual mean soil moisture which affects how well plants can grow is projected to increase marginally in some places but will decrease across much of the western portion of the region. Annual runoff, will decrease (-30% to -40%) across already dry western portion of the region (Middle East) and increase (up to 40%) in some of the flood-prone regions in south Asia and in Southeast Asia. Fisheries, a major source of livelihoods and protein for many countries, are also projected to be negatively impacted, especially in South and Southeast Asia. Climate change will challenge water supply issues in South Asia and may adversely affect agricultural and livestock sustainability. It may also complicate the unsustainable consumption of groundwater for irrigation and other uses in some locations.

Researchers are conducting series of simulation studies to project climate in 2030s (average of 2021-2050) over India using regional climate models (RCMs). Simulations for the 2030s indicate an all-round warming, associated with increasing greenhouse gas concentrations, over the Indian subcontinent. The rise in annual mean surface air temperature by the 2030s is projected to be 1.7°C to 2.0°C **(Table 1)**. The daily maximum and daily minimum surface air temperature (1°C to 4°C) may

Table 1 – Climate change projections for 2030 relative to the 1961–1990 baseline	
Parameters	**Projections**
Annual surface Temperature	1.7°C to 2°C
Precipitation	3-7% (with reference to 1970)
Extreme precipitation	Increase in intensity by 2-12%
Extreme temperature	High night temperatures over south peninsula, central and northern India, more day time warming in central and northern India
Sea level rise	0.18 m- 0.59 m in 2090-2099 with respect to 1980-1999
Cyclones	Decrease in frequency but intensity of monthly cyclonic disturbances will increase during monsoon season
Source: (6)	

intensify. Night temperatures are likely to rise more over the south peninsula and central and northern India. Central and northern India may experience an increase in day time warming. A small increase in annual precipitation is indicated by 5% to 13% with less number of rainy days and more intense rainfall. The temperature increases are likely to be much higher in Rabi season than in Kharif **(Table 2)**. It is projected that by the end of the 21st century, rainfall over India will increase by 10–12%, and the mean annual temperature will increase by 3-5°C. The projected increase in drought and flood events could result in greater instability in food production and threaten livelihood security of farmers. Although the cyclonic disturbances along the coastal regions are likely to decrease with respect to the 1970s, they might be more intense in the future. Sea level is expected to continue to rise over the next several decades with the rate of thermal expansion of 1.3±0.7 mm/year. These changes are likely to increase the pressure on Indian agriculture, in addition to the present yield stagnation, competition for land, water and other resources.

Researchers are conducting series of experiments on different aspects under both field as well as controlled conditions to assess and estimate the impacts of the weather abnormalities and events, triggered by climate change, on various crop categories including cereal, pulses, oilseeds, fodder, horticultural and plantation crops. Some experiments use open top chambers (OTCs) or Free Air CO_2 Enrichment (FACE) facilities to quantify the effect of elevated CO_2. The OTCs with hot air blowing and temperature gradient tunnels (TGTs) are being employed to quantify the impacts of elevated temperature. Results from such experiments indicated that rise in atmospheric temperature reduces the biomass and yield of rice, green gram, pigeonpea, wheat, chickpea, mustard, onion and tomato. The elevated CO_2 concentrations resulted in higher biomass production in wheat, groundnut, sunflower, onion, tomato, coconut, cocoa, castor, sweet potato and arecanut (16). Field experiment at IARI in small temperature tunnels and FACE showed that yield reduced gradually with rise in temperature but Rice, chickpea and mustard showed greater thermal tolerance, while Wheat and groundnut proved to be more thermal sensitive. Greengram and potato showed intermediate level of tolerance for increased temperature (24). Results indicated that elevated CO_2 could alleviate the negative impact of temperature increase up to 4°C in chickpea and 5°C in mustard. In other crops, elevated CO_2 could counter-effect the temperature increase to lesser extent with least degree in wheat (1.5°C). The projected climate change will not only influence the production and productivity of crops but is also likely to influence the quality of produce. Studies indicated that protein content of wheat, green gram and chickpea grains increased marginally with rise in temperature, whereas it decreased with rise in CO_2 level. Oil content of sunflower and mustard seed increased under elevated CO_2 condition. In tomato, antioxidants were higher at elevated CO_2 concentrations. Increased storage temperature adversely affected the keeping quality of coconut copra and oil (16). Increase in temperature may have significant effect on the quality of cotton, fruits, vegetables, tea, coffee, aromatic and medicinal plants. The nutritional quality of cereals and pulses may also be moderately affected thereby affecting the nutritional security of India, where cereals are the primary diet. The quality of basmati rice is adversely impacted as temperatures increase above the optimal level (9).

Global simulation studies indicated that by 2080-2100, temperature increase may lead to 10-40% loss in crop production in India (7). In developing countries, climate change will cause yield declines for the most important crops in South Asia with more pronounced declines in irrigated yields for all the crops like rice and wheat. Rainfed maize and wheat will experience positive impacts in yields **(Table 3)**. The

Table 2 – Changes in rainfall and temperature during crop growing season		
Crop growing season	**Kharif**	**Rabi**
Increase in maximum temperature (°C)	0.79-2.82	0.85-3.07
Increase in minimum temperature(°C)	1.36-3.28	1.85-3.06
Rainfall (% change)	-22to 60%	-60 to 36%
Source: (13)		

Table 3 – Climate-change induced impacts on yields of major foodgrains

Crops	Change in yield in 2050 (%)	
	Developing countries	Developed countries
Wheat, irrigated	–28.3	-5.7
Wheat, rainfed	-1.4	3.1
Rice, irrigated	-14.4	3.5
Rice, rainfed	-1.3	17.3
Maize, irrigated	-2.0	-1.2
Maize, rainfed	0.2	0.6

negative effects of climate change on crop production are more in South Asian region with 14% decline in rice production, a 44-49% decline in wheat production, and a 9 to 19% fall in maize production relative to the no–climate-change scenario i.e., business as usual **(Table 4)**. The studies conducted in India also showed similar trend of decline in agricultural production with climate change but at varying magnitudes. Analysis indicated the possibility of loss of 4-5 million tonnes in wheat production with every rise of 1°C throughout the growing period. Climate change is likely to reduce yields of maize and sorghum by up to 50%, depending upon the region. The yield loss in maize and sorghum due to rise in temperature is likely to be offset by the projected increase in rainfall during monsoon and the spatio-temporal variations in projected changes in temperature and rainfall are likely to lead to differential impacts in the different regions. In the case of rainfed maize, the projected yield loss is up to 35%. In some districts of coastal Andhra Pradesh, rainfed maize yields are likely to increase by 10%. As maize and sorghum have a C4 photosynthetic system and hence do not have a relative advantage at higher CO_2 concentrations (5). Studies conducted on soybean have projected 50% increase in yield for a doubling of CO_2 in central India (16, 25). However, a 3°C rise in surface air temperature almost offsets the positive effects of doubling of CO_2 concentration. Mustard yields are likely to reduce in both irrigated and rainfed condition with spatial variation. The productivity of irrigated rice is likely to change +5 to –11% in most of the regions. A majority of the region is projected to lose the yield by about 4%. However, irrigated rice in parts of southern Karnataka and the northern-most districts of Kerala are likely to gain. In coastal regions irrigated rice yields are projected to reduce by about 10% to 20%. However, in some coastal districts of Maharashtra, northern Andhra Pradesh and Orissa, irrigated rice yields are projected to marginally increase by 5%. On the other hand, rainfed Rice yields are likely to be in the range of –35% to +35%. Most regions of Western Ghats are likely to lose rice yields by up to 10%. Irrigated rice is able to benefit due to the CO_2 fertilisation effect as compared to rainfed Rice, which is supplied with less amount of fertilisers (10). In case of Wheat late-sown areas are projected to suffer more than the timely-sown ones. Central and south-central regions of India may be more affected. Despite CO_2 fertilisation benefits in future climate, Wheat yield is projected to be reduced in areas with mean seasonal maximum (>27°C) and minimum temperatures (>13°C) Adaptation options, such as change in sowing times, and increased and efficient use of inputs, could not only offset yield reduction, but could also improve yields.The potato yield in IGP region is also projected to decrease by ~2.5, ~6 and ~11% in 2020, 2050 and 2080, respectively (11). On all India basis the mustard grain yield is projected to decrease by ~2% in 2020 (2010–2039), ~7.9% in 2050 (2040–2069) and ~15% in 2080 (11). With increasing temperatures, it is anticipated that there may be an all-round decrease in apple production in the Himalayan region and the line of production may shift to higher altitudes (5). Although many studies indicate adverse impacts of climate change, there are certain beneficial effects of climate change such as projected improvement in coconut yields in west coast (30%) and east coast specifically in the north coastal districts of Andhra Pradesh (10%) of India (16). However, some areas like Gujarat coast, some districts in eastern coast, southwest Karnataka, parts of Tamil Nadu and parts of Maharashtra may show reduction in coconut yields by up to 24 to 40% (5).

Vulnerability of Indian agriculture at the district level was assessed using three core components: (i) exposure to hazards, (ii) sensitivity to climate change, i.e. the amount of damage expected to be caused by a particular event and (iii) adaptive capacity to recover from stress **(Figure 1)**. It was observed that the districts located in the eastern and southern parts of Uttar Pradesh, Bihar, Rajasthan central and parts of north-east India are most vulnerable, whereas the districts in Punjab and Haryana are less vulnerable due to higher adaptive capacity.

Table 4 – Climate-change effects on crop production in South Asia

Crops	Effects on crop production			
	2000 (M mt)	2050 (M mt)	% Change (BAU)	% Change with climate change
Rice	119.8	168.9	41	-14.3
Wheat	96.7	191.3	97.9	- 43.7
Maize	16.2	18.7	15.7	- 18.5
Millets	10.5	12.3	16.5	- 19.0
Sorghum	8.4	9.6	13.9	- 19.6

Source: (3)

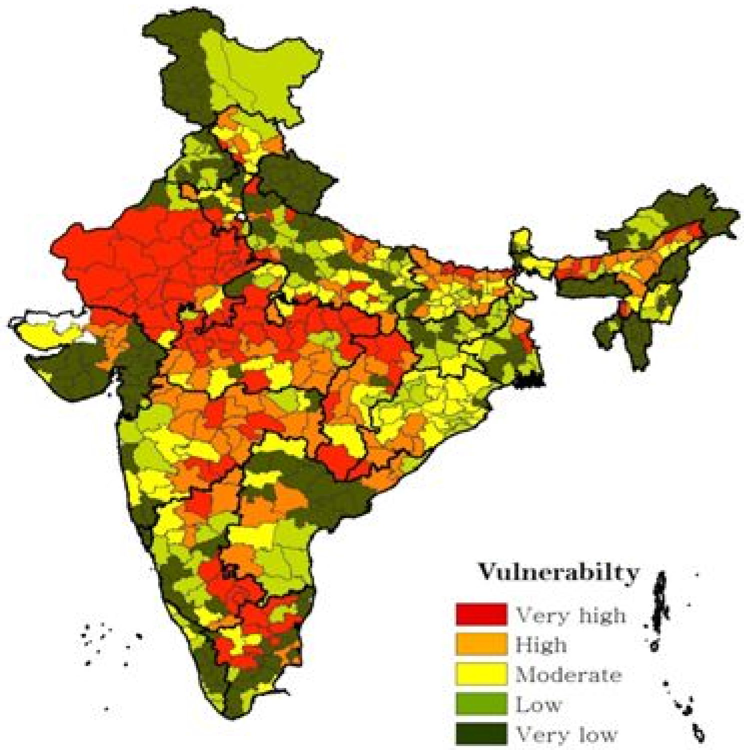

***Figure 1 - Vulnerability of Indian agriculture to climate change: A district level assessment for 1960-2010*.**
Source: (22, Sehgal et al. unpublished)

Impacts on Dairy, Fishery and Poultry

Studies conducted by National Dairy Research Institute, Karnal, indicated that global warming is likely to lead to a loss of 1.6 Mt in milk production by 2020 and 15 Mt by 2050, if no adaptation measures are taken. Lactating cows and buffaloes have higher body temperature and are unable to maintain thermal balance. Body temperature of buffaloes and cows producing milk is 1.5-2°C higher than their normal temperature, therefore more efficient cooling devices are required to reduce thermal load of lactating animals (16). Climate change would increase water, shelter, and energy requirement of livestock for meeting projected milk demands (26).

A rise in temperature could have important and rapid effects on the health of fish and their geographical distributions. With warming of sea surface, the oil sardine is able to find temperature to its preference, especially in the northern latitudes and eastern longitudes, thereby extending the distributional boundaries and also establishing fisheries in larger coastal areas (27). The dominant fish, the threadfin breams, have responded to increase in Sea Surface Temperature (SST) by shifting the spawning season off Chennai coast. For instance, during past 30 years period, the spawning activity of *Nemipterus sp.* reduced in summer months and shifted towards cooler months. Analysis of historical data showed that the Indian mackerel is able to adapt to rise in sea surface temperature by extending distribution towards northern latitudes, and by descending to depths (5, 28).

In recent years the phenomenon of Indian Major Carps maturing and spawning as early as March is observed in West Bengal with its breeding season extending from 110-120 days. As a result, it has been possible to breed them twice a year at an interval of 30-60 days (1). In poultry sector, heat stress was significantly high in heavy meat type chickens as compared to light layer type and native type chickens. Increase in temperature from 31.6°C to 37.9°C decreased feed consumption and egg production (16).

Climate Resilient Technologies for Indian Agriculture

Given the potential risks associated with climate change, a serious effort on characterizing, analyzing and understanding adaptation is needed. It is necessary to understand as to who is undertaking the adaptation or what the interests of diverse stakeholders in this activity are. Individuals and societies are vulnerable to climate risks and this vulnerability can act as a driver for adaptive resource management. Some adaptations by individuals are undertaken in response to climate threats, often triggered by individual extreme events. Some other adaptations are to be undertaken by the government on behalf of the society, sometimes even in anticipation of a change, undertaken often in response to a single event. A distinction has to be drawn between planned adaptation, expected to be undertaken by the governments on behalf of society, and autonomous adaptation undertaken by individuals. Much adaptation by farmers, fisherman, and coastal dwellers will be autonomous and facilitated by their own social capital and resources. Analogues of adaptation should be complemented with policy and social science research on the existing adaptive capacity of government, society and markets to deal with climate perturbations. Among these approaches, the key issue is the identification of successful adaptations in the regions where the biggest risk and physical vulnerability persist.

Mitigation and adaptation are

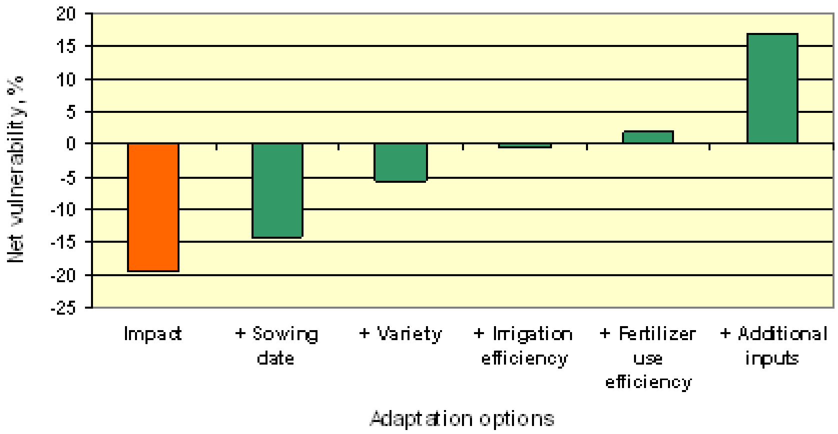

Figure 2 – Adaptation options for reducing the vulnerability of agriculture

Source: Aggarwal et al. (Unpublished)

often viewed as separate activities, the former aiming to reduce greenhouse gas emissions and the latter helping to adjust the expected increases in emission of greenhouse gases. However, when it comes to agriculture, the adaptation measures can also generate significant mitigation effects, making them a highly worthwhile investment. It is unequivocal that concerted efforts are required for mitigation and adaptation to reduce the vulnerability of Indian agriculture to the adverse impacts of climate change and making it more resilient. However, mitigation options take a longer time to affect the climate change, whereas adaptation options are required almost immediately. The adaptive capacity of the poor farmers is often limited because of their subsistence agriculture and low formal education. Therefore, simple, economically-viable and culturally-acceptable adaptation strategies have to be developed and implemented. With current adaptation practices the crop yield losses can be compensated to some extent **(Figure 2)**. Fortunately, the adaptation strategies have several mitigation co-benefits. However, the co-mitigation benefits of such strategies may be highly location-specific.

Potential adaptation strategies to deal with the impacts of climate change are developing cultivars tolerant to heat and salinity stress and resistant to flood and drought, modifying crop management practices, improving water management, adopting new farm techniques such as resource conserving technologies (RCTs), crop diversification, improving pest management, better weather forecasts and crop insurance and harnessing the indigenous technical knowledge of farmers. Some of these strategies are discussed.

Climate-ready Crop Varieties

Development of new crop varieties with higher yield potential and resistant to multiple stresses (drought, flood, salinity) will be the key to maintain yield stability. Improvement of germplasm of important crops for heat tolerance should be one of the targets of breeding programmes. Similarly, it is essential to develop tolerance to multiple abiotic stresses as they occur in nature. Germplasm with greater oxidative stress tolerance may be exploited as oxidative stress tolerance, where plant's defense mechanism is targeting abiotic stresses. In addition, it is important to improve the root efficiency for the uptake of water and nutrients from soil. Genetic engineering could play a pivotal role for 'gene pyramiding' to pool all desirable traits in a plant to get the 'ideal plant type' which may also be 'adverse climate tolerant' genotype. As several research efforts have been on to convert rice from C3 to C4 crop, such efforts may also be useful for improvement of radiation and water use efficiency of other crops as well. Conventional breeding has to be strengthened by wedding with modern biotechnological approaches like marker-assisted breeding and transgenic development. Molecular biology and biotechnology has immense potential to overcome formidable challenges of agriculture by providing resilience to plant against biotic and abiotic stresses.

Water-Saving Technologies

Efficient use of natural resources such as water is highly critical for adaptation to climate change. With hotter temperatures and changing precipitation patterns, water will further become a scarce resource. Serious attempts towards water conservation, water harvesting and improvement of irrigation accessibility and water use efficiency will highly be essential for crop production and livelihood management. On-farm water conservation techniques, micro-irrigation systems for better water use efficiency and selection of appropriate crop need based irrigation has to be promoted. Principles of increasing water infiltration with improvement of soil aggregation, decreasing runoff with use of contours, ridges, vegetative hedges and reducing soil evaporation with use of crop residues mulch could be employed for better management of soil-water. There is a need for technologies and investments that improve water management efficiency. Well-timed deficit irrigation can make a substantial difference in productivity in places with limited access to irrigation. In non-irrigated areas, water conservation and water harvesting techniques are the only possible alternatives to poor farmers. However, adoption of such practices may not be technology intensive, but will certainly require investment in capacity building and agricultural extension. Rain water harvesting can help in fulfilling water demand in water scarce regions. Improved irrigation methods like drip irrigation, sprinkler irrigation and use of laser-aided land leveling can also help in increasing water-use efficiency. Laser aided leveling provides smooth and leveled field, which allows ideal water distribution with negligible losses of water. It facilitates uniformity in the placement of seed/seedlings and fertiliser which helps good plant stand, enhanced nutrient use efficiency and increased yield (20). In the rural areas Rain Water Harvesting can be carried out through gully plug, contour bund, gabion structure, percolation tank, check dam, recharge shaft and dugwell recharge.

Changing Planting Date

Adjustment of planting dates to minimize the effect of high temperature induced spikelet sterility can be used to reduce yield instability so that the flowering period does not coincide with the hottest period. Adaptation measures to reduce the negative effects of increased climatic variability as normally experienced in arid and semi-arid tropics may include changing the cropping calendar to take advantage of the wet period and to avoid extreme weather events (e.g. typhoons and storms) during the growing season. Cropping systems may have to change to include growing suitable cultivars, increasing cropping intensities or crop diversification. For example, there is an urgent need for diversification of the conventional puddled transplanted rice and intensively tilled wheat to other cropping systems such as maize-wheat, pulse-wheat, maize-pulse, oilseed-wheat and direct-seeded rice-wheat. The latter systems have less demand for water and nutrient (with legume) and use resources more efficiently thereby increasing farmers' income and exhorting less pressure to the natural resource base.

Integrated Farming System

Small and marginal farmers having subsistence farming need assistance for making their agriculture profitable so they can improve their livelihoods and eventually help themselves escape from the ill effects of climate change. Integration should be made among crop production, livestock, agro-forestry and fish production to improve the production, income and livelihood. This is especially important for small and marginal land holding situations as prevailing in large part of the country. Major emphasis should be given on development of diverse technologies for optimization of farm resources, increased economic return and improved sustainability in an integrated farming systems approach. New opportunities will be explored to introduce in the system to complement and synergize the productivity and income.

Crop Diversification

Crop diversification helps ameliorating the adverse effects of seasonality on family incomes and peak labour demands, reduce risk due to fluctuating monsoonal patterns, help asset improvement on farms, conserve rainwater and save irrigation water, facilitate easier weed and nitrogen management, reduce water logging, and often result in better yield. Research have indicated that large areas of rice-fallows in the Indo-Gangetic Plains having adequate soil moisture can be brought under crop diversification and intensification with legumes and other crops (4). Diversification to other crops like pulses and oil seeds with less demand for water and nitrogen seems to be a good option for this region. Crop diversification and its associated changing tillage, crop establishment, nutrient management and harvest practices will affect yield and soil fertility status.

Integrated Pest Management

Changes in temperature and variability in rainfall would affect pests incidence and virulence of major crops. This is because climate change will potentially affect the pest/weed-host relationship. Some of the potential adaptation strategies could be (1) developing cultivars resistance to pests; (2) integrated pest management with more emphasis on biological control and changes in cultural practices, (3) pest forecasting using recent tools such as simulation modelling, (4) alternative production techniques and (5) identification of crops, as well as locations, that are resistant to infestations and other risks. Climate change will lead to change in the pest and disease infestation of crops. Higher temperature can shorten dormant periods, speeds up pest and disease growth and changes the dynamics of these populations and their resistance. Crops, varieties and traits that are resistant to pests and diseases will improve producers' ability to adapt to climate change. Biotechnology stands out as a promising tool to facilitate the development of traits and varieties that could help to mitigate and adapt to climate change (2). Herbicides and other inputs that reduce competition from weeds can improve productivity and thereby serve to mitigate GHGs emissions associated with bringing additional land under cultivation.

Crop Insurance

Crop insurance schemes, private and public, should be put in place to help the farmers in reducing the risk of crop failure due to extreme climatic events. However, information is needed to frame out policies that encourage effective insurance opportunities. Micro-finance has been a success among rural poor including women. Low-cost access to financial services could be a boon for vulnerable farmers. Growing network of mobile telephony could further speed up SMS-based banking services and help farmers have better integration with financial institutions. There is a need to develop sustainable insurance system, while the rural poor are to be educated about availing such opportunities.

Conservation Agriculture

Conservation agriculture and the Resource Conservation Technologies (RCTs) have proved to be highly useful to enhance resource or input-use efficiency and provide immediate, identifiable and demonstrable economic benefits such as reductions in production costs, savings in water, fuel and labour requirements and timely establishment of crops resulting in improved yields. Yields of wheat in heat and water-stressed environments can be raised significantly by adopting the RCTs, which minimize unfavourable environmental impacts, especially in small and medium-scale farms. Zero-tillage can allow farmers to sow wheat sooner after rice harvest, so the crop heads and fills the grain before the onset of pre-monsoon hot weather.

Improved Weather-based Agro-Advisory

Farmers with awareness of weather events can respond by planting more appropriate crops or varieties. Forecasting of weather events will help farmers in adopting suitable crop management options. Prediction of extreme climatic events should be done well in advance to minimize crop loss. Major innovations in response to climate variability will take the form of improved information through global monitoring and forecasting. Improved micro-climate modelling can also enable more accurate understandings of the dynamics of weather events. These weather based agro-information can be made available to farmers through audio and visual media and also effectively through mobile phone networks. Weather forecasting and early warning systems will be very useful in minimizing risks of climatic adversaries. Information and communication technologies could greatly help researchers and administrators develop contingency plans.

Improved Nutrient Management

The adverse impact of climate change on crop yield could be compensated with more and efficient use of plant nutrients. For example, yield reduction because of late sowing of rice as a result of delayed onset of monsoon can be compensated with higher application of N. Improved nutrient management also offers promising opportunities for mitigating GHG emission. For example, technologies including matching N supply with crop demand, using proper fertiliser formulation and right method of application, use of N-transformation inhibitors, optimizing tillage, irrigation and drainage and growing of suitable crop cultivars are some of the potential technologies to reduce N_2O emission (18). The most efficient management practice to maximize plant N uptake and minimize its losses is to synchronize supply with plant demand. The strategy to achieve this objective is site-specific nutrient management (SSNM). Demand-driven N use can be achieved using a leaf colour chart (LCC), an easy-to-use and inexpensive tool for determining nitrogen status in plants. Use of the LCC promotes timely and efficient use of N fertiliser in rice and wheat and minimizes fertiliser related pollution of surface water and groundwater. Using controlled release fertiliser to release nutrients in synchrony with plant growth it is possible to provide sufficient nutrient and reduce losses. More efficient use of fertiliser nitrogen results when application of fertiliser coincides with the period of rapid plant uptake. Application of small amounts of fertiliser N several times rather than applying the whole amount together have proved to be more useful for supplying N for plant growth. Foliar application of fertiliser N is another way of supplying N during periods of rapid plant growth and N demand. Nitrogen use efficiency can be increased by use of urease inhibitors and nitrification inhibitors.

Marketing and Supply Chains

Investments in improved harvesting, processing, storage, distribution and logistics technology and necessary training investments can pay off as well as improved crop yields in terms of gains to consumers and the climate adaptation (8). As climates become hotter and precipitation more erratic, the potential for post-harvest losses may increase and thus improved transport and storage become even more important.

Harnessing the Indigenous Technical Knowledge of Farmers

Farmers in south Asia, often poor and marginal, are experimenting with the climatic variability for centuries. There is a wealth of knowledge of a range of measures that can help in developing technologies to overcome climate vulne rabilities. There is a need to harness that knowledge and fine-tune them to suit the modern needs. Traditional ecological knowledge of people developed and carried which have stood the test of time could provide insight and viable options for adaptive measures. Anthropological and sociological studies have highlighted the importance of community based resource management and social learning to enhance their capacity to adapt to the impacts of future climate change. Tribal and hill knowledge systems are pregnant with potential indigenous practices used for absorption and conservation of rainwater, nutrient and weed management, crop production and plant protection. Their belief systems effectively help in weather forecasting and risk adjustment in crop cultivation.

Fertiliser Management for Climate Change Adaptation and Mitigation

Fertiliser has played a key role in increasing crop yield following the widespread adoption of green revolution technology, but now yield growth rates are declining. With the degradation of natural resources and changing climatic conditions in the region there are increasing concerns about food security. Fertiliser can have a role in reducing poverty and food insecurity if the right policies and practices are developed. The fertiliser use efficiency is very low (30 to 40%) and most of the applied nutrients are lost and may become even lower in the future climate change scenario. Lost nutrients represent inefficiencies and productivity and economic losses; losses that negatively affect farm profitability and potential degradation of soil, water and air quality. Application of fertiliser, particularly N fertiliser, has increased food production tremendously all over the world. However, it also contributes towards global warming and ozone layer depletion through emission of nitrous oxide (N_2O), a greenhouse gas (GHG). The N_2O emissions from Indian agricultural soils is estimated to be 0.26 million tonnes (19). Emission of N_2O is increasing over the years because of increased N fertiliser use as the N fertiliser contributes about 77% of the emission. Agriculture offers promising opportunities for mitigating N_2O emission. The practices that deliver added N more efficiently to crops often reduce N_2O emissions. Technologies including matching N supply with crop demand, using proper fertiliser formulation and right method of application, use of N-transformation inhibitors, optimizing tillage, irrigation and drainage and growing of suitable crop cultivars are some of the potential technologies **(Table 5)**. The adverse impact of climate change and variability on crop yield could be compensated with more and efficient use of N. The most common strategies suggested for climate change adaptation includes alternate land-use management, intensification of agriculture, crop diversification and conservation agriculture. All these strategies require a suitable N management strategy, which might be different from the conventional way of N management. Use of various nitrification inhibitors can reduce GWP by about 10-15% **(Table 5)**. Management of N can also help in improving crop quality, which is likely to be deteriorated under climate change scenarios. Because of higher level of CO_2 concentration in the atmosphere and lower N availability in soil under climate change scenarios, the crops would have higher carbohydrate content, lower protein content and higher C:N. Additional and efficient N application under elevated CO_2 can compensate the deteriorating quality of crop. The adverse impact of climate change and variability on crop yield could also be compensated with more and efficient use of N (17).

Initiatives of Government of India for Developing Climate Resilient Agriculture

India recognizes that for ensuring country's food security both in the short- and long-term and making agriculture sustainable and climate-resilient, appropriate adaptation strategies have to be developed. The country has initiated timely action to address the problems of climate change. India's first National Action Plan on Climate Change (NAPCC) identified eight core "national missions" outlining existing and future policies and programs addressing climate mitigation and adaptation of which five are directly or indirectly related to agriculture **(Table 6)**. These efforts have provided valuable inputs in terms of the regional and national level impacts of climate variability and climate change on major food grains crops, horticulture and livestock production. The National Mission for Sustainable Agriculture (NMSA) seeks to address issues regarding sustainable agriculture, and aims at devising appropriate adaptation strategies for ensuring food security, enhanced livelihood opportunities and economic stability. The NMSA has identified 10 key dimensions for adaptation. **Table 7** enlists the various policies/programmes of the Government of India under NMSA with their key objectives, aimed at promoting sustainable development. These include improved crop seeds, livestock and fish culture; water use efficiency; pest management; improved farm

Table 5 – Potential and constraints of greenhouse gas mitigation options in Rice-Wheat system in India

Technology	Mitigation (%)	Yield (%)	Constraints
Methane from Rice field			
Intermittent drying	25-30	90-100	Assured irrigation
Direct-seeded Rice	30-50	90-100	Machine, herbicide
SRI	25-30	95-110	Labour, irrigation
Short duration variety	15-20	95-115	-
Nitrous Oxide from Soil			
Demand-driven N use	10-15	105-110	Knowledge, tool
Nitrification inhibitor	10-15	105-110	Cost, incentive
Carbon Sequestration in Soil			
Conservation agriculture	5-10	95-110	Continuity
Integrated nutrient management	5-10	95-110	Manure availability, cost

Source: (18, 19)

Table 6 – National Action Plan on Climate Change and their objectives in relation to agriculture	
National Action Plan	**Objectives**
1. National Water Mission	20% Improvement in water use efficiency
2. National Mission for Sustaining the Himalayan Ecosystem	To conserve biodiversity, forest cover, and other ecological values in the Himalayan region
3. National Mission for a Green India	Afforestation of 6 million hectares of degraded forest lands Expansion of forest cover from 23% to 33% of India's territory
4. National Mission for Sustainable Agriculture	Climate adaptation in agriculture through the development of climate-resilient crops, · Expansion of weather insurance mechanisms and agricultural practices
5. National Mission on Strategic Knowledge for Climate Change	Better understanding of climate science, impacts and challenges Climate Science Research Fund, Improved climate modeling and Increased international collaboration

Source: (15)

practices; improved nutrient management; agricultural Insurance; credit support; markets; access to information and livelihood diversification.

The country has initiated National Livestock Mission (NLM) for increasing livestock production while protecting the environment, preserving animal bio-diversity, ensuring bio-security and farmers' livelihood. The activities like making of hay/ silage, establishment of fodder banks and densification, feed enrichment processing units, establishment of feed processing units, etc. will reduce production of green house gases. A major initiative has also been taken in fisheries with the launch of National Fisheries Development Board (NFDB) to achieve sustainable development of the fisheries sector.

Building upon the early initiatives of 10th Five Year Plan, the Ministry of Agriculture launched the National Initiative on Climate Resilient Agriculture (NICRA) which is a flagship program of the Indian Council of Agricultural Research (ICAR) to undertake systematic long term research on the impacts and adaptation of Indian agriculture to climate change covering not only grain crops but also horticulture, natural resource, livestock and fisheries. The program covering

Table 7 – Different programmes under NMSA with their specific objectives

Policy/programme	Features
National Policy on Agriculture	♦ Attain output growth rate in excess of 4% per annum based on efficient use of resources
Integrated Watershed Management Programme	♦ Restore ecological balance by harnessing, conserving and developing degraded natural resources such as soil, vegetative cover and water
National Watershed Development Project for Rainfed Areas	♦ Sustainable management of natural resources, enhancement of agricultural production, restoration of ecological balance in the degraded and fragile rainfed ecosystems, reduction in regional disparity between irrigated and rainfed areas, and creation of sustained employment opportunities for the rural community including the landless
Rashtriya Krishi Vikas Yojana	♦ Assist states in the development and implementation of district-level agricultural plans (based on local agro-climatic conditions) and bring about quantifiable changes in the production and productivity of various components of agriculture and allied sectors
National Food Security Mission	♦ Aims at increasing production of rice, wheat and pulses through area expansion and productivity enhancement in a sustainable manner, restoring soil fertility and productivity at the individual farm level
National Project on Organic Farming	♦ Aims to promote production, promotion and market development of organic farming in the country
Micro Irrigation Scheme	♦ Increase the area under efficient methods of irrigation like drip and sprinkler irrigation
Weather Based Crop Insurance Scheme	♦ Aims to mitigate against the likelihood of financial loss on account of anticipated crop loss resulting from incidence of adverse conditions
National Horticulture Mission	♦ To provide holistic growth of horticulture sector through regionally differentiated strategies
National Project on Management of Soil Health and Fertility	♦ Facilitate and promote Integrated Nutrient Management (INM) through judicious use of chemical fertilisers in conjunction with organic manures and bio-fertilisers

Source: (15)

more than 21 central institutions and several state level agricultural universities is one of the largest projects in any developing country. It not only addresses strategic research but also demonstrates the best bet practices on farmers' fields to cope with current variability. This is being carried out in 130 vulnerable districts of the country.

The Ministry of Agriculture through ICAR has undertaken extensive capacity building of farmers, scientists and extension workers at various levels on the impact of climate change on agriculture and promotion of locally appropriate adaptation strategies. For example, in key climatically vulnerable areas of the country, the Government is promoting crop varieties tolerant to abiotic stresses, practices of improved water and nutrient management, particularly micro-irrigation, conservation agriculture, crop diversification, pest surveillance and integrated pest management. These coupled with improved agro-advisories and weather based crop insurance are likely to help farmers to cope with climate variability and minimize risks. To synergize extension mechanism National Mission on Agriculture Extension & Technologies (NAME&T) has been made operational from 2014-15.

In rainfed agriculture, which is more risk prone and covers nearly 60% of the net sown area, ICAR has evolved several *in situ* and *ex situ* water conservation technologies and improved dryland agriculture technologies, which are being upscaled through the Integrated Watershed Management Program (IWMP) and Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS). The ICAR is also planning to upscale the demonstration of best bet practices through NICRA through nearly 160 districts in the 12th Five Year Plan. These practices cover four modules, i.e., natural resource management, crop production, livestock and fisheries and institutional interventions. The experiences of NICRA will be provided to NMSA for larger adoption in the country. All major programmes such as National Food Security Mission (NFSM), Mission for Integrated Development of Horticulture (MIDH), National Mission on Sustainable Agriculture (NMSA), National Mission on Oilseed & Oil Palm (NMOOP) and Rashtriya Krishi Vikas Yojana (RKVY) emphasize on water harvesting & resource conservation in farmer's field. A dedicated component namely On-Farm Water Management (OFWM) under NMSA is operational to promote water management in farmers' field focusing on enhancing on-farm water use efficiency.

The ICAR has also prepared a district level climate vulnerability atlas for undertaking these location specific adaptation activities both by public, private and non-governmental sector. India is also initiating newer policy in terms of efficiently using water, energy and fertiliser in agriculture. One of the major issues, the country is facing is the inter-annual variability in rainfall and temperature affecting one part or other of the country every year. To face this challenge the ICAR has prepared District Level Contingency Plans for implementation in the years to come.

Women play a significant and crucial role in agricultural development and allied fields in the main crop production, livestock production, horticulture, post harvest operations, agro/social forestry, fisheries, etc. To ensure greater involvement of women in agricultural development, it has been emphasized in the Guidelines of the DAC schemes for making at least 30% of the allocated budget under the components for women farmers.

Adaption to agriculture in the face of climate changes needs to be countered by using state-of-the-art techniques and methodologies for assessing crop forecasts and drought situation in advance. Forecasting Agricultural output using space, agro meteorological and land based observations (FASAL) is a multi-institutional programme, which integrates the activity from many organisations such as Mahalanobis National Crop Forecast Centre (MNCFC), Space Applications Centre (ISRO), India Meteorological Department (IMD), Institute of Economic Growth and State Agricultural Departments aiming at providing multiple pre-harvest production forecasts of crops at National, State and District levels. There is also a Inter-Ministerial Mechanism like Weather Watch Group (WWG) representing IMD, Ministry of Water Resources, Ministry of Consumer Affairs, Department of Fertilisers and Dept. of Economic Affairs to monitor various parameters i.e., rainfall, water storage, sowing status, fertilisers, pest & diseases, prices and availability of seeds to make necessary arrangement in the wake of extreme climatic events and other calamities.

Integrated Farming System (IFS) is being promoted through introduction of supplementary farm-based livelihood support activities apart from crops/cropping system to provide greater resilience & sustenance to farmer in the wake of extreme climatic events. To promote agro-forestry as a farming system, National Agro-forestry Policy has been formulated by Government of India. Agriculture needs to diversify to tackle adverse situation/extreme condition and relief based management approach to contain impact of any such extreme climate variability. Therefore, apart from the long term & short term approaches, Crisis Management Plan for Drought has been prepared to enable the Central and State Governments to minimize its impact in emergency situation.

CONCLUSION

Global climate change is considerably affecting and will continue to affect the food supply and access through direct and indirect effects on crops, soils, livestock, fisheries and pests. Therefore, concerted efforts are required for mitigation and adaptation to reduce the vulnerability of Indian agriculture to the adverse impacts of climate change and making it more resilient. A win-win solution is to start with such mitigation strategies that are needed for sustainable development. There is a need to develop policy framework for implementing the adaptation and mitigation options so that the farmers are saved from the adverse impacts of climate change. Development and operationalization of adaptation strategy necessitate socio-psychological empowerment of farmers besides developing competencies in acquiring knowledge and skills related to adaptation practices. The envisaged adaptation of agriculture to climate change will require substantial funds to support vigorous and concerted efforts by national and international research and development institutions. To promote the adoption of climate-resilient strategies we need to facilitate transfer of climate-smart technologies from developed countries to developing countries so that the in-house efforts of adaptation gets further strengthened. Possible sources of technical and funding supports should be identified for promoting climate-resilient adaptation technologies. Exchanging information and providing technical advice on improving efficiency, productivity and resilience of agriculture at regional and national scales should be considered. Besides, capacity building and awareness on multiple advantages of climate-smart, sustainable agricultural technologies should be promoted.

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