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Climate Change-Implications for Agriculture and Food Security

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Abstract

The warning signs of global warming have appeared everywhere, right from increased concentration of greenhouse gases in the atmosphere, to increasing temperatures, and occurrence of extreme events like droughts, floods, intense rains, and cyclones, besides melting of glaciers and rise in sea levels. The objectives of this paper are to present likely scenarios, risks to agriculture, food security and livelihoods arising out of climate change in coming few decades. Further, the paper analyses the projected situations in 21st century with special reference to climate change impacts on groundwater resources, agricultural and horticultural crops besides dairy and allied sectors in Indian context. In addition to carrying forward the analyses on the underlying forces of climate change, it gives a comprehensive account of climate profile of India. It suggests various measures required to minimize the adverse effects of climate change on environment. It also explains in depth the salient features of India's National Initiative on Climate Resilient Agriculture (NICRA), launched in 2011, and how it is being implemented at micro-level in villages/clusters to develop climate change adaptation and mitigation measures in a technological, management, and socio-economic level to protect the losses to food and commercial crops. At the same time, NICRA aims to protect the livelihoods of vulnerable people in rural areas by giving them access to information, technical and institutional support from the Government and agricultural research Institutions to manage their crops and allied enterprises that may happen to be under climate change threat. The paper also analyses the framework of The National Mission for Sustainable Agriculture (NMSA) launched in 2010 under the domain of National Action Plan on Climate Change that was announced earlier in 2009. The major objectives of NMSA mission are to develop adaptive crop varieties by conserving, enriching and exploiting the genetic pool of agricultural and allied sector crops to lessen the adverse impacts of climate change on their yields and provide the much needed food security to Indian population. The paper concludes by recommending that India should invest in research and development (R&D) activities for introducing high-yielding new generation of climate change adaptable crops, along with improved farm management practices specific to such climates, in order to maximize nutrient utilization and water use efficiencies that are essential in raising real time crop yields. Also, alternate cropping systems should be practised to prevent crop failures from extreme events.

Key words: climate change, greenhouse gases (GHGs), intergovernmental panel on climate change (IPCC), carbon dioxide (CO_2), emissions, temperature, floods, climate, livelihoods, south-west monsoon, rainfall, rainfed, crop yields, adaptation, mitigation, carbon sequestration, sustainable, resilient, and food security

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INTRODUCTION

The global warming has become a serious issue since the last three decades. According to the Fifth Assessment Report (AR5) of the United Nations' Inter-Governmental Panel on Climate Change (IPCC), 2014, there is an evidence of warming of earth's atmosphere and ocean systems. As expected, the human society is the single most significant factor responsible for enhanced global warming since 1950. Since the damage has already been done in the last 4–5 decades, the control has to be done on emergency basis as the 30 year period between 1983–2012 was reported to be warmest on record in the last 1400 years.

The globally averaged combined land and ocean surface temperature data as calculated by a linear trend has shown a warming of 0.85°C over the period 1880–2012.[1] Also, between 1992 and 2011, the polar ice sheets in Greenland and Antarctica have been found to be shrinking, and contributing to sea level increases. Besides, there has been a record increase of greenhouse gases (GHGs) concentration-mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the atmosphere, which has been unprecedented in the last 800,000 years.[1]

In fact, mean global temperatures have been rising since about 1850, primarily due to the accumulation of greenhouse gases in the atmosphere owing to the burning of fossil fuels i.e. coal, oil and gas to meet increasing energy demand. Also, on account of the spread of intensive agriculture to meet increasing food demand globally, deforestation has taken place in many parts of the world. Further, owing to the increased economic growth, which has been accompanied by an increase in urban global population, along with corresponding increases in total populations in many nations and parts of the world, development of agriculture has taken place on industrial lines. This is evident from the development of food processing industry, which along with the growth of logistics industry, has given rise to local, national and global supply chains of food products. As a result, the process of global warming shows no signs of slowing down and is expected to bring about long-term changes in weather conditions globally.[2]

These climate related changes are likely to impact food security in terms of its availability, accessibility, utilization and overall food system stability. Whenever there is a drought or excessive floods in top producing countries, the effects are felt in global food markets.[7] This is reflected in increased market prices to consumers for food items, and effects are more pronounced in rural areas where crops fail, livelihood opportunities are lost, and affected rural communities and small farmers are unable to cope.[2,3]

On the global level, food system stability currently depends more on climate than it was 200 years ago. The impacts of climate change on food security are likely to be more severe in areas and locations where rainfed agriculture is still the primary source of food and income.[2]

Climate and its Measurement

Climate refers to the conditions of earth's lower surface atmosphere at a specific location, while weather refers to the day-to-day fluctuations in these conditions at the same location. The variables that are commonly used by meteorologists to measure daily weather phenomena are air temperature, precipitation, atmospheric pressure, humidity, wind speed and direction, besides sunshine and cloud cover.[2]

When the weather related variables are measured systematically at a specific location over several years, a record of observations in the form of data is generated from which averages, ranges, maximums and minimums for each variable can be computed, or derived.

Global climate is the average temperature of the earth's surface and the atmosphere in contact with it, and is measured by analysing hundreds to thousands of temperature records collected from land and sea stations across the world. Regional climates are patterns of weather that affect a significant geographical area. The main factors determining it are: (i) differences in temperature due to distance from the equator and seasonal changes in the angle of sun-rays as the earth rotates; (ii) planetary distribution of land and sea masses; and (iii) the worldwide system pertaining to general circulation of winds, which arise owing to temperature difference between the equator and the poles. Local climates affect and prevail over a very small geographical area, extending to only a few kilometres. On the other hand, if area involved is indeed very small say for example a plot of crop under experimentation or plants kept in greenhouse with controlled humidity and temperature, and then the climate there is referred to as a micro-climate.[2]

Definitions of Climate and Climate Change Terminology

Climate

The synthesis of weather conditions in a given area, characterized by long-term statistics i.e. mean values, variances, and probabilities of extreme values for the meteorological elements in that area.[2]

Climate Variability

In general usage, this term denotes the inherent characteristic of climate that can be shown to describe changes of climate over time. The degree of climate variability can be explained by the differences between long-term statistics of meteorological elements calculated for different periods.[2]

The term is often used to denote deviations of climate statistics over a given period of time i.e. during a specific month, season or year from the long-term climate statistics relating to the corresponding calendar period. In this respect, climate variability is measured by those deviations, which are usually termed as anomalies.[2]

Climate Change (World Meteorological Organization [WMO usage])

This term in general covers all forms of climatic disturbances or fluctuations or differences in a given geographical area for its meteorological elements from their corresponding long-term statistics calculated for different periods but relating to the same area, irrespective of their statistical nature or physical causes. Climate changes may result from such factors as changes in solar emission, long-term changes in the earth's orbital elements, natural internal processes of the climate system, or anthropogenic causes such as increasing atmospheric concentrations of CO_2 and other greenhouse gases.[2]

Climate Change (United Nations Framework Convention on Climate Change [UNFCCC usage])

It refers to a change of climate that is attributed, directly or indirectly, to human activity, that alters the composition of the global atmosphere and that is in addition to the natural climate variability observed over comparable time periods.[2,4]

Climate Change (Intergovernmental Panel on Climate Change [IPCC Usage])

Climate change as referred to in the observational record of climate occurs because of internal changes within the climate system or due to the interaction among its components, or because of changes in external system, caused by natural reasons or because of human activities. It is generally not possible to make clear distinction and attributions between these causes.

Projections of future climate change reported by IPCC generally consider the influence on climate of only anthropogenic increases in greenhouse gases and other human related factors.[2,4]

The Inter-Governmental Panel on Climate Change (IPCC) was established in 1988 by United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear view on the current state of Climate Change and its potential environmental and socio-economic consequences. IPCC defines climate change as 'a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity'.[4,5]

IPCC Projections

IPCC panel (AR 5, 2014) predicts that by the end of the 21st century, the global surface temperature increase is expected to be greater than 1.5°C vis-a-vis the period between 1850 and 1900 in most situations, and may even surpass 2.0°C increase under worst situations in different parts of the world. Consequently, the water cycle across the world will change, and there would be more disparity between wet and dry regions. Oceans are expected to be warmer, which might affect the water circulation patterns. Further, increases in the rate of CO_2 production, and its consequent absorption by oceans would result in the acidification of the oceans that might be harmful to the aquatic life, including fish, which are a source of food for human beings.[1]

Earlier, in its previous report, Intergovernmental Panel on Climate Change[4] had forecast a rise in temperature between 0.5°C–1.2°C by 2020 for the Indian region (South Asia), followed by an increase in temperature between 0.88–3.16ºC by 2050 and 1.56°C–5.44°C by 2080, depending upon other developments in the future. In terms of crop planting and growth seasons, the temperature increase was expected to be much higher during the winter (Rabi) seasons than in summer/rainy (Kharif) seasons. Also, the rainfall is expected to increase by 15–40% by the turn of this century during all months except during December-February when it is likely to decrease. The simulations also indicated that there would be an overall increase in frequency of short duration one day rainfall scenarios in the country. Such events have been seen in monsoon seasons in recent years.[6]

MATERIALS, METHODS, AND MAJOR DATA SOURCES

The present study is based on secondary data and information that were collected from the publications, records of Indian Meteorological Department, Ministry of Agriculture, Government of India(GOI), Ministry of Statistics & Program Implementation(MOSPI), GOI, Ministry of Environment and Forests(MOEF), GOI, Indian Institute of Tropical Meteorology(IITM), GOI, Reserve Bank of India (RBI), Economic Survey of India, GOI, United Nations Inter-Governmental Panel on Climate Change (IPCC), Food and Agriculture Organization(FAO), Rome publications. This was supplemented by information drawn from several important comprehensive research studies done by premier research institutions operating under the aegis of Indian Council of Agricultural Research (ICAR), GOI such as Indian Agricultural

Research Institute (IARI), New Delhi, and a few other leading Institutions /Universities in Punjab, Uttar Pradesh, and Uttaranchal in north Indian states besides in southern Indian states of Tamil Nadu and Karnataka. The research findings in the form of research papers by several leading researchers in various areas of specialization in agriculture- notably in agronomy, plant breeding, soil science and agro-meteorology, plant pathology and entomology were collected from edited or individual standalone publications. The data and information sources for development of this paper are mentioned in the detailed References listing that appears at the end of this paper.

The key variables identified for this study were Green House gases (GHGs), temperature and rainfall, and their combined effect on agriculture, and vulnerable rural populations.

Scope

The global scenarios of climate change with special reference to India in context of Indian agriculture, its vulnerable populations in rural and semi-urban areas, besides mitigation strategies to handle climate change impact by government agencies, research scientists, and farmers at regional and local level have been analysed and discussed in this paper.

Objectives of the Study

1. To understand the causes and driving forces of climate change, and projections for 21st century.
2. To study the impact of climate change that poses risk to agriculture and rural livelihoods, and measures for adaptation and mitigation
3. To undertake the detailed analysis of climate profile of India with respect to annual monsoon/rainfall activity on long-term trends basis
4. To discuss the observed changes in climate and weather events in India
5. To understand the perceivable impacts of climate change on agricultural crops, dry-land agriculture, groundwater resources, and other allied sectors
6. To analyse the National Initiative on developing climate resilient agriculture.

DRIVING FORCES OF CLIMATE CHANGE

Increased Industrial Activity and Greenhouse Gases Accumulation

Major sectors of industrial activity contributing to the economic development of nations across the globe are the main drivers of the climate change. Increased production of goods and services, changes in the production structure, increased transportation, higher demand for all kinds of consumer goods, etc., contribute to a higher pressure on the atmosphere thereby increasing the greenhouse gases (GHGs) concentration. The most important aspect of industrial and economic development is the ever increasing demand for energy. At present the world's economy runs on fossil fuels. The combustion of coal, oil and natural gas and derived products provide energy to almost all economic activities. The emission of Carbon Dioxide (CO_2) is a residual product of burning these fossil fuels. Also changes in land use pattern, deforestation and land clearings are important driving forces leading to a rise in Carbon Dioxide emissions.[5,6,7]

As a result of industrial production, and consumption activities, changes have been observed with regard to the following: (i) excessive use of environmental resources, (ii) changes in land use, and (iii) increased levels of emissions with regard to chemicals, harmful gases, effluents, waste materials, radiation, and noise levels that are entering into our ecosystems via air, water and soil media.[5]

While some of the industrialized countries have managed to de-link sulphur dioxide emissions from economic growth, but they have been not successful in controlling carbon dioxide (CO_2) emissions. It is thus clear that as long as the world economy is dependent on carbon-based energy sources derived from coal, oil, and natural gas, the economic growth cannot be separated from CO_2 emissions. On the other hand, the proportion of renewable energy – derived from other sources like wind, solar, geothermal, biofuels – constituted about one percent of the world's primary energy supply in 2006.[7]

Green House Gases-Sources and Their Effects

Greenhouse Gases (GHGs) are gases in the atmosphere that absorb and emit radiation. Earth's most abundant GHGs are water vapor, carbon dioxide (CO_2), atmospheric methane, nitrous oxide (N_2O), Ozone (O_3) and chloro-fluro-carbons (CFCs). Greenhouse effect is a process by which radioactive energy leaving an earth's surface is absorbed by these greenhouse gases. The ability of the atmosphere to capture and recycle energy emitted/reflected by earth's surface is the defining characteristic of the greenhouse effect. Global warming is on increase owing to the strengthening of greenhouse effect mostly due to industrial and consumption related activities on the earth. The pressures related to climate change being considered are the greenhouse gas emissions caused by economic activities. CO_2 is the most important greenhouse gas, and originates mainly from the combustion of fossil fuels and biomass. However, other greenhouse gasses like methane, nitrous oxide and CFCs also contribute to climate change. Methane is mainly produced by domesticated animals such as dairy cattle and livestock, rice cultivation, gas flaring and mining activities. Nitrous Oxide mainly originates from agricultural land management, animal manure management, combustion of fossil fuels, and the production of fertilizers and nitric acid.[5,6,8,9]

CO_2 is the most important anthropogenic GHG as it constitutes about 70% of the total emissions. CO_2 is released into atmosphere by burning of fossil fuel (56.6%), deforestation and decay of biomass (17.3%), and from activities associated with agriculture and allied sectors. However, the largest contributor of GHG emissions between 1970 and 2004 were industries connected with energy supply, and transport.[5,6,10]

Before the Industrial Revolution, the atmospheric concentration of carbon dioxide was about 280 ppm (parts per million).[8] When continuous observations began at Mauna Loa in 1958, carbon dioxide concentration was roughly recorded at 315 ppm. On May 9, 2013, the daily average concentration of carbon dioxide measured at Mauna Loa surpassed 400 parts per million for the first time on record.[11] During the week of April 6, 2015, average carbon dioxide (CO_2) levels touched 404.02 ppm, the highest-ever in recent human history. This was 15% above the levels, which have been defined maximum for earth i.e. 350 ppm. The recording was reported by Earth System Research Laboratory at Hawaii, USA, which has been also recording CO_2 levels since 1958.[12]

The global atmospheric concentration of Methane has increased from pre-industrial value of about 715 ppb (particles per billion) to 1774 ppb in 2005 (The Intergovernmental Panel on Climate Change 4th Annual Report.[4] Methane is generated due to the following activities:

Agriculture Energy sources like biomass, agricultural and forest residues burning, rice cultivation, livestock enteric fermentation; Coal mining and handling and flaring of natural gas systems; Waste disposal; Land-use change; Forestry; and Shifting Cultivation practice.[5,6,13]

Indirect GHG emissions through agricultural production are generated through production of fertilizers and pesticides, operation of farm machinery and due to on farm energy use besides production of agricultural equipment in industries.[6,13] Further, direct CHG emissions from agriculture are due to: agricultural production itself which releases carbon/CO_2 into atmosphere, land use change generates carbon emission, Nitrous oxide (N_20) emission due to application of Nitrogenous fertilizers and burning of agricultural/forest residues which is accompanied by release of Methane (CH_4) into atmosphere.[13]

Projections of Climate Change over India for the 21st Century

Scenarios predicted by IPCC forecast temperature increases up to 4.5°C or higher by 2080, depending on a range of factors that human based activities may take. Many experts believe that a rise of 2°C is the threshold beyond which impacts are likely to be severe, and dangerous to environmental systems.[14]

Annual mean surface temperature by the end of century may rise between 3°C–5°C under A2 scenario and between 2.5°C–4°C under B2 scenario of IPCC, with warming more pronounced in the northern parts of India.[4,15]

According to Assessment Report, AR4 of IPCC that was released in 2007 the following scenarios were visualized:

1. Daily and seasonal temperature patterns could change with increases in both maximum and minimum temperatures, with increasing number of hot days and nights.[8,9]
2. Rainfall patterns could change significantly, with subtropical regions expected to get lower rainfall and the northern latitudes likely to get increased rainfall. Further, the distribution of rainfall within a year or season could also change.[9]
3. Rising temperatures would lead to extreme weather events like heat waves, heavy rainfall, and intense storms and cyclones. Seasonal climate patterns, as reflected by annual monsoons, could also undergo changes.[8,9]
4. Further, the melting of polar ice-caps would lead to a rise in sea levels, which will pose a threat of submergence to coastal communities and many inhabited islands, or such countries that are based on islands.[15]
5. Global warming will lead to changes in the ocean waters. Due to increased CO2 concentration, oceans will acidify, resulting in adverse consequences for marine life-both of animal and plant origin.[8]

Indian summer monsoon (ISM) i.e. south-west (SW) monsoon develops owing to complex interactions between land, ocean and atmosphere parameters. The simulation of ISM's mean pattern as well as variability on annual and seasonal basis is a challenging task. Some simulations by IITM, Pune, have indicated that summer monsoon intensity may increase beginning from 2040 onwards, and is projected to increase 10% by 2100 under A2 scenario of IPCC AR4 Report, 2007.[4, 15]

RISKS TO AGRICULTURE, LIVELIHOODS AND FOOD SECURITY

Threats to Agriculture, and Rural Livelihoods

Agriculture, the source of our food and fibre supplies is facing threats due to climate change. Experts believe that climate change has the potential to irreversibly damage the natural resource base on which agriculture depends. The relationship between climate change and agriculture is a two-way traffic; agriculture contributes to climate change in several ways and climate change in turn adversely affects agriculture. The reality is that even without climate change, agricultural systems in developing countries are under capacity stress due to rising populations, which demand more production from per unit of cultivated farmlands, inland fisheries and forests. Besides, water is in short supply in many parts of world, particularly in developing countries where agriculture plays a dominant role in economy and in the lives of majority of population, or local populations as the case may be due to dependence of their livelihoods on food, fibre and fuel supplies from agriculture, and forests. Thus climate change is a risk multiplier for vulnerable populations in poor regions of the world due to adverse impacts on crops, and water sources.[8,10,15,16]

Agriculture is currently constrained in its capacity to respond to poverty and generate a range of livelihood options in rural areas. Farming systems are diverse and range between small scale labours intensive to large capital intensive farming systems. In developing countries, limited rural employment opportunities coupled with the continued dependence of small farmers on small scale holdings have diminished the viability of subsistence agriculture due to increasing input prices, relatively stagnant farm gate prices, availability of subsidized imports and limited market surplus available with farmers.[9,16]

In addition, the application of modern biological, chemical and mechanical technologies, in particular, are suitable for farms and/or farming systems which have conditions that enable them to produce commodities for trading in vertically integrated value chains. Nevertheless, in many parts of the developing world, small scale producers with the government and private sector, or civil society organizations support – both technical and financial, also have intensified their production systems and benefited from increasing market integration. Though the productivity per unit of land and per unit of energy use is much higher in these small and diversified farms than the large intensive farming systems in irrigated areas, they (small farms) continue to be neglected by formal organizations that are capable of providing agricultural knowledge, science and technology (AKST) application techniques to help them overcome environment and resource constraints. The challenge for AKST is to address these small-scale farms in diverse ecosystems and to create realistic opportunities for their development.[16]

According to International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) (2009) projections, global food markets were expected to be tightened with the emergence of a few large global players owing to increasing market concentration in a few hands and growth of global retail chains in developing countries, coupled with the scarcity of natural and physical resources. Real world prices of most cereals and food products were projected to increase in the coming decades, dramatically reversing past trends with serious implications on global food security. Millions of small-scale producers and landless labour in developing countries and underdeveloped markets are expected to face reduced access to food and livelihoods. The food security challenge is likely to worsen if markets and market-driven agricultural production systems continue to grow in a "business as usual" mode. By 2050, the number of severely malnourished children will increase to 80 million, concentrated mainly in South Asia and sub-Saharan Africa.[16]

Additionally, there are potential and actual risks to rural livelihoods and incomes due to loss of bio-diversity, and crop failures resulting from deficient rains, dry spells, or non-availability of water for irrigation, and instances of fall in yields in such situations. Extreme events like Tsunami can destroy the marine and coastal ecosystems, biodiversity, and the ecosystem goods, and services which they provide to poor people who survive on coastal livelihoods, mainly on fisheries for livelihoods.[2,9,14,16]

Risks to Food Security

Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Food sovereignty is defined as the right of peoples and sovereign states to democratically determine their own agricultural and food policies. Using appropriate AKST can contribute to radically improved food security. It can support efforts to increase production, enhance the social and economic performance of agricultural systems as a basis for sustainable rural and community livelihoods, rehabilitate degraded land, and reduce environmental and health risks associated with food production and consumption.[2,16]

According to FAO, food security depends more on socio-economic conditions than on agro-climatic factors alone, and on access to food rather than the production or physical availability of food. In order to evaluate the potential impacts of climate change on food security, one has to determine i) how incomes of poor will be affected by climate change, ii) whether the country will be able to earn enough foreign exchange to buy food from other countries, and iii) whether the food surplus countries will be able to increase their commercial exports, and/or food aid to poor countries that are likely to be affected by climate change.[2,17]

At local and regional level, food security vulnerability to climate change begins with biophysical effects on individual farms with respect to their crops and livestock, and on the systems in which they are managed. Thus climate change adversely impacts livelihoods in rural areas, while the national and international markets transmit economic signals of climate change by affecting domestic prices of food and other essential items of consumption, which are important for vulnerable populations in rural and urban areas. Pre-existing conditions of vulnerability make poor people more exposed to the effects of climate change, as social, economic and agro-environmental circumstances may become more severe with climate change.[18]

Public sector research has yet to offer a range of viable rural management and agronomic practices for crop and livestock systems that are appropriate for water-restrained dry lands and poor farmers. Private sector research, concentrated on internationally traded crops, is less likely to find such projects profitable, at least in the immediate future. Yet, public funding for such research in these crops and regions will be necessary if we are to address the needed changes in organizational and institutional arrangements to respond to the constraints imposed by poor management systems. Such investments will likely assist in limiting natural resource degradation and environmental deterioration, and contribute to decreasing the poverty and pockets of hunger that currently persist in the midst of prosperity.[16,18] Due to an increased integration of energy demand with supplies from agricultural crops in coming decades, there could be disruptions in food grains production as well as in other commercial crops like sugarcane, and oilseeds, which are meant for human consumption. The competition from bio-fuels industry for coarse cereals like maize (corn) besides for some oilseed crops like oil palm, is also growing which coupled with climate change can put pressure on limited land and water resources that are required to produce sufficient food for growing global populations.[19,20]

Impacts on Food Crops and Allied Sectors

Food production in India is sensitive to climate changes such as variability in monsoon rainfall and temperature changes within a season. Studies by Indian Agricultural Research Institute (IARI), New Delhi and others indicate greater expected loss in the Rabi (winter) crop. Every 1°C rise in temperature has the ability to reduce annual wheat production by 4–5 million tons in the country. Minor changes in temperature and rainfall have significant effects on the quality of horticultural crops, such as fruits, vegetables, and medicinal plants besides plantation crops like tea, and coffee. Changes in temperature and precipitation can affect the production and quality of Indian aromatic "basmati" rice crop, which continues to be in demand in national and international markets due to its fine flavour, taste, grain size, and appearance.[5,9,15]

According to a study done by the International Maize and Wheat Improvement Center (CIMMYT), there is a strong possibility of climate becoming too hot in coming decades for wheat crop along the Indo-Gangetic Plains of South Asia, which grows 15% of the world's wheat in an area of 13 million hectares that is spread over in Pakistan, northern India, Nepal and Bangladesh. According to the study, by 2050 more than half of this area may become heat-stressed for wheat crop, and resulting in relatively shorter season for the crop.[14]

Pathogens and insect populations multiply rapidly due to their getting favourable temperature and humidity combination. Changes in these parameters may lead to faster multiplication of their populations. Other impacts on agricultural and related sectors include lower yields from dairy cattle and decline in fish breeding, migration, and harvests. If current trends in climate change continue, global projections estimate a loss of 10–40% in crop production by 2100.[6,14,21]

Impacts on Crop Yields, and on Agricultural Resources

In mid- to high-latitude regions, moderate increases in temperature can have small beneficial impacts on crop yields; in low-latitude regions, even moderate increases in temperature are likely to affect crop yields negatively. Such negative impacts are already visible in many parts of the world; additional warming will have additional negative impacts in all agricultural regions. Water scarcity and the timing of its availability will increasingly constrain production. Climate change will require a new look at water storage to cope with the impacts of more and extreme precipitation, higher intra and inter-seasonal variations, and increased rates of evapo-transpiration in all types of ecosystems. Extreme climate events (floods and droughts) are increasing and expected to amplify in frequency and severity and there are likely to be significant consequences in all regions for food and forestry production and food insecurity. There is a serious potential for

future conflicts over habitable land and natural resources such as freshwater. Climate change is affecting the distribution of plants, invasive species, pests and disease vectors and the geographic range and incidence of many human, animal and plant diseases is likely to increase.[16]
Land and water resources for food production are much more stressed today than they were in the past, both in quantitative and qualitative terms, due to soil degradation, salinity of irrigated areas and competition from industry for these two scarce resources. Also, increases in crop yields have slowed down due to technology saturation for many crops in many countries. The issue facing the world is whether we have sufficient land and water resources, both existing and unused resources to expand food production to handle climate change, which would negatively affect the production potentials of agricultural resources in many areas of the world.[19]

Based on results of several studies, negative impacts of climate change on crop yields found to be more pronounced than positive impacts. The smaller numbers of studies that indicate positive gains in yields are mainly from high latitude areas. Climate change has already affected wheat and maize yields downwards in many parts of the world. Yield losses have been smaller for rice and soybeans.[1]

CLIMATE PROFILE WITH SPECIAL REFERENCE TO MONSOONS/ RAINFALL IN INDIA

Climatic Regions and Seasons

Physical Geography of India

India possesses a variety of climatic regions, ranging from tropical in the southern states to temperate and alpine in the northern and Himalayan north India, where elevated regions/states receive regular snowfall in winter months. Apart from Himalayas, which act as a barrier to winds from central Asia, India's climate is also influenced by Thar Desert in western region, covering mostly Rajasthan state. Thus northern states in India, including some central regions of the country, exhibit continental climate with severe summer conditions that alternates with cold winters when temperatures in certain northern-most areas fall to freezing point. In contrast, coastal regions of the country, there is variation in warm climate and frequency of rains is relatively high. Overall, India is characterised by strong temperature variations in different seasons ranging from mean temperature of about 10°C in winter to about 32°C in summer season.[22]

Climate and Monsoon Seasons in India

India's climate is influenced primarily by two major rainy seasons. Due to severe heat of summer months, the northern Indian landmass becomes hot and draws moist winds blowing over the oceans in the form of south-west monsoon. This is most important feature of the Indian climate as more than two-thirds to three-fourths of the annual rainfall is received during a short span of four months (June to September). Variability in the timely onset, withdrawal and quantum of rainfall during the monsoon season has significant impacts on water resources, power generation, agriculture, economics and ecosystems in the country.

During winter months, there is reversal of winds as dry and cold air from the northern latitudes, especially from north-eastern India blows over the Indian landmass, and it results in north-east monsoon during relatively cooler month of October, and winter months of November and December, as mostly experienced in northern, north-western, north-eastern and central parts of India. It is also called retreating south-west monsoon, or post south-west monsoon period. In spite of lower cumulative rainfall during north-east monsoon, coefficient of variation with respect to rainfall received is higher during the months of November, December, January and February.[22]

There is a large variation in the amounts of rainfall received at different locations. The rainfall pattern exhibits a large spatial as well as temporal variability, which brings about the variability in the climate induced seasons in the country.

Winter Season

India Meteorological Department (IMD) has put January and February in winter season months category. For north-western parts of the country, December is also included in the winter season. The cold air flow from the Siberian region, significantly affects northern and central India during these months. The mean temperatures vary from 14°C–27°C during January. The average daily minimum temperatures range from 22°C in southern most regions/areas of India, to 10°C in the northern plains, and as low as 6°C in Punjab state.[22]

Rains during this season generally occur over the western Himalayas, the north-eastern parts/states, besides in southern states of Tamil Nadu and Kerala. Moreover, western disturbances and flow of western winds into India are main rain bearing system in northern and eastern parts of the country during winter months.[22]

Pre-Monsoon Season/ Summer Season (March, April and May)

Temperatures begin to increase all across India in March and by April; the interior parts of the peninsula record mean daily temperatures of 30°C–35°C. Central Indian land mass becomes hot with daytime maximum temperatures reaching about 40°C at many locations. Many areas in Gujarat, North Maharashtra, Rajasthan and North Madhya Pradesh exhibit high day-time and low night-time temperatures during this season. Maximum temperatures rise sharply exceeding 45°C by the end of May, and early June resulting in harsh summers in the north and north-west regions of the country. However, weather remains mild in coastal areas due to the influence of land and sea breezes.[22]

Additionally, weather over land areas is influenced by thunderstorms accompanied by rain and sometimes with hail in this season. Local thunderstorms with rain lasting for short durations occur over the eastern and north-eastern parts in states of Bihar, West Bengal, and Assam. Thunderstorms are also observed over central India, and at times they extend up to southern state of Kerala as well. Hot and dry winds accompanied with dust winds blow frequently over the plains of north-western India.[22]

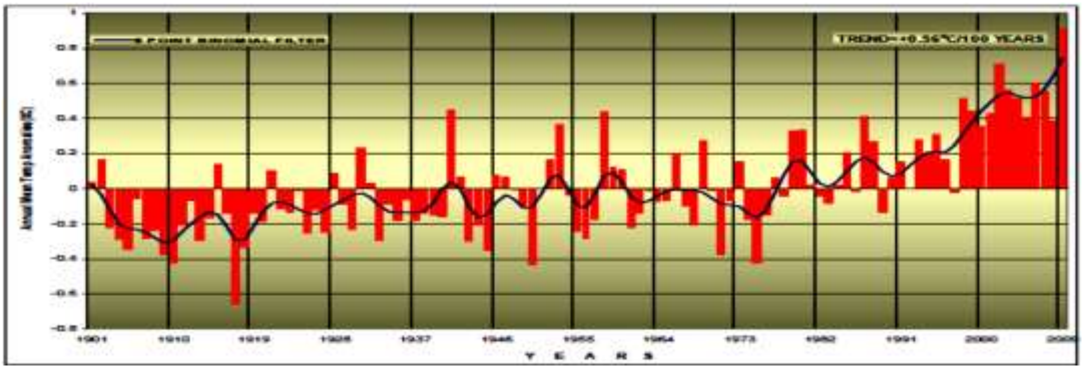

Fig.1. *India: Annual Mean Temperature Departures Based on 1961-1990 Average for 1901-2009.*

Source: Indian Meteorological Department (IMD), Pune 2010.

South-West Monsoon/ Summer Monsoon Season (June, July, August and September)

The south-west (SW) monsoon is the most significant feature of the Indian climate. The season is spread over four months, but the actual rainfall during this period at a particular geographical location depends on the onset and monsoon withdrawal dates. It varies from less than 75 days in western parts of Rajasthan, to more than 120 days over the south-western regions of the country contributing to about 75% of the annual rainfall in the season. The onset of the SW monsoon normally starts over the Kerala coast, the southern tip of the country by May 31/June 1, advances along the Konkan coast (western India coast) in early June and covers the whole country by middle of July. However, onset occurs about a week earlier over islands in the Bay of Bengal. The monsoon is a special phenomenon exhibiting regularity in onset and distribution within the country, but inter-annual and intra-annual variations are observed. The monsoon is influenced by global and local phenomenon like El Nino, northern hemispheric temperatures, sea surface temperatures, and snow cover on Himalayas. The monsoonal rainfall is accompanied by active spells in the form of widespread rains over most parts of the country, and the pattern of coverage often breaks due to reduced or little rainfall over the plains. However, heavy rains sweep across the foothills of the Himalayas resulting in flooding over the plains.[22]

Cyclonic systems of low pressure called 'monsoon depressions' are formed in the Bay of Bengal during this season. The distribution of rainfall over northern and central India depends on the path followed by these depressions. SW monsoon usually withdraws from Rajasthan by 1st September and from north-western states/regions of India by 15th September. It withdraws from almost all parts of the country by 15th October and is replaced by a northerly continental airflow called North-East Monsoon. The retreating monsoon winds intermittent showers along the east coast of Tamil Nadu, but rainfall moves away from coastal regions.[22]

Post-Monsoon or Northeast Monsoon or Retreating SW Monsoon Season (October, November and December)

North-East (NE) monsoon or post-monsoon season takes place due to north-easterly winds that blow over the Indian subcontinent. Meteorological subdivisions namely Coastal Andhra Pradesh Rayalaseema, Tamil Nadu, Kerala and South Interior Karnataka receive good amount of rainfall accounting for about 35% of their annual total in these months.

Many areas of southern state of Tamil Nadu, and a few areas of Andhra Pradesh and Karnataka receive rainfall during this season due to the storms forming in the Bay of Bengal. Mortality to human and livestock lives, and losses to property of rural people are observed due to heavy rainfall, strong winds and storms in the coastal regions. By this season, day temperatures start plummeting all over the country. The mean temperatures over north-western regions decline from around 38°C in October to 28°C in November. Decrease in humidity levels and clear skies over most parts of north and central India after mid-October are characteristics features of this season.[22]

South West Monsoon Season Rainfall (June, July, August & September) patterns

For the country as whole, mean monthly rainfall during July (286.5 mm) is highest and contributes about 24.2% of annual rainfall (1182.8 mm). The mean rainfall during August is slightly lower and contributes about 21.2% of annual rainfall. June and September rainfall are almost similar and contribute 13.8% and 14.2% of annual rainfall, respectively. The mean south-west monsoon (June, July, August & September) rainfall (877.2 mm) contributes 74.2% of annual rainfall (1182.8 mm). Contribution of pre-monsoon (March, April & May) rainfall and post-monsoon (October, November & December) rainfall in annual rainfall is generally the same (11%).[22]

Historical Trends in Rainfall

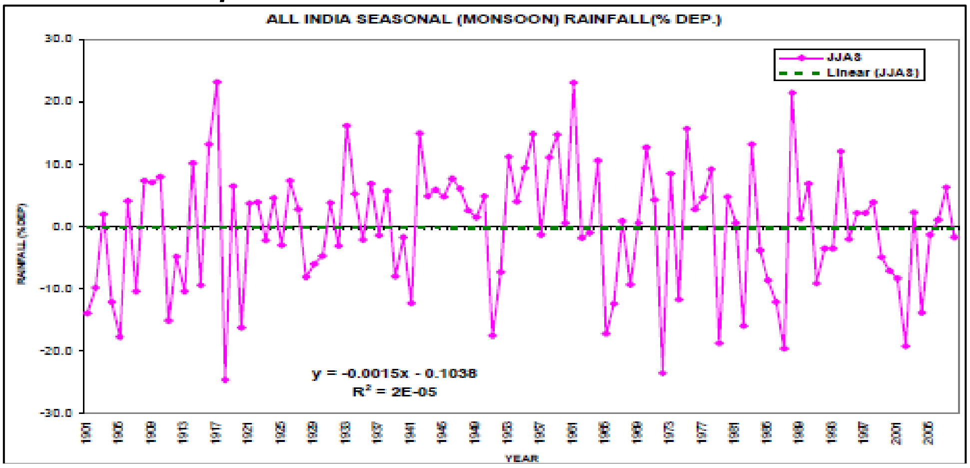

***Fig.2.** India: Trends in Rainfall Across the Country During Monsoon Season Basis for the Period 1901-2009.*

Note: JJAS refers to June, July, August and September when south-west monsoon is active, when majority of the annual rainfall is received in the country.
Source: IMD, Pune 2010.

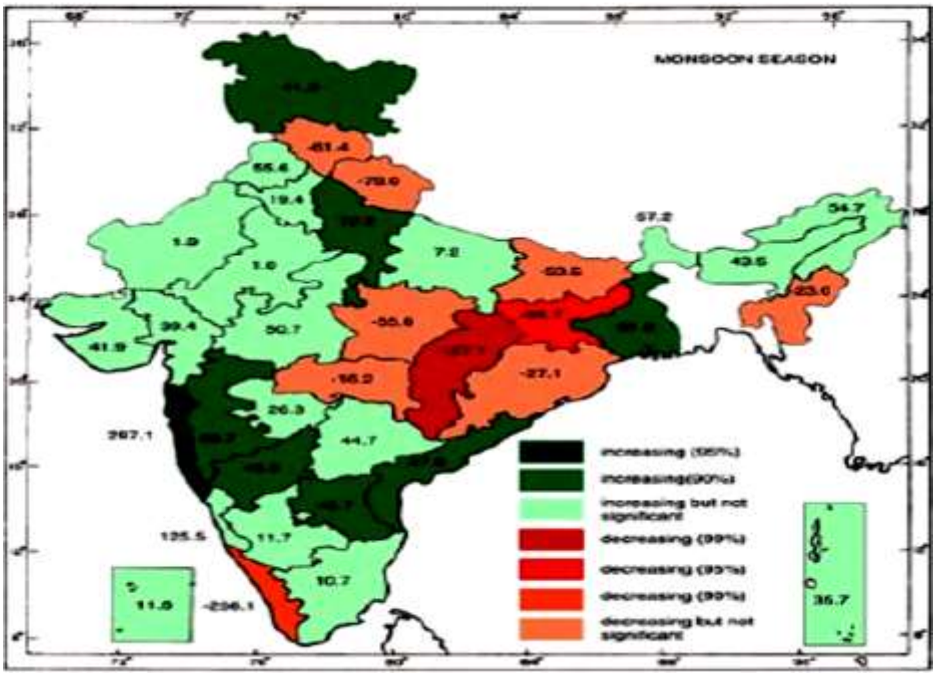

***Fig.3.** India: Trends in Rainfall During Monsoon Season-Increase/Decrease Measured in mm-Level of Significance of Rainfall Data is Depicted by Different Colours for the Period 1901-2003.*

Source: IMD, Pune, 2010; IITM, Pune, 2010.[23]

All India Average Rainfall*:* The IITM rainfall series was analysed for detection of trends and it was found that All India summer monsoon season (June to September) rainfall as well the all India rainfall for all the four monsoon months does not show any significant trend.[23]

Trends in Regional Distribution of Rainfall*:* Even though no significant trend has been noticed in annual/ monsoon rainfall at all India levels, trends (both increasing and decreasing) have been observed in the spatial distribution of the rainfall.[22]

Analysis based on IMD rainfall series indicated that during the monsoon season, three subdivisions viz. Jharkhand, Chattisgarh, Kerala show significant decreasing trends, and eight subdivisions viz. Gangetic West Bengal, West Uttar Pradesh, Jammu & Kashmir, Konkan & Goa, Madhya Maharashtra, Rayalaseema, Coastal Andhra Pradesh and North Interior Karnataka show significant increasing trends.[22,23]

SUMMARY OF MAJOR FINDINGS

Observed Changes in Climate and Weather Events in India[15]

Surface Temperature

At the national level, an increase of 0.4°C in surface air temperatures has occurred in the last 100 years. As a result, a warming trend has been observed along the west coast, in central India, the interior peninsula, and north-eastern India. However, cooling trends have been observed in north-west India and parts of south India.[15]

Rainfall

While the observed monsoon rainfall at the all-India level does not show any significant trend, regional monsoon variations have been recorded. A trend of increasing monsoon and seasonal rainfall has been observed along the western coastline of India, northern Andhra Pradesh, and north-western India (+10% to +12% of the normal over the last 100 years). On the other hand, a decreasing trend of monsoon/seasonal rainfall has been observed over eastern Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala, with the variation ranging between -6% to -8% of the normal rainfall over the last century.[15]

Rise in Sea Level

Using the records of coastal tide gauges in the north Indian Ocean for more than 40 years, it has been estimated that sea level rise was between 1.06–1.75 mm per year. These observations and estimates are consistent with 1–2 mm per year global sea level rise estimates of IPCC.[8,15]

Impacts on Himalayan Glaciers/Water Resources

The glaciers of Himalayas form a significant source of water for the perennial rivers in India such as the Indus, the Ganga, and the Brahmaputra. Decrease in snow cover due to melting of glaciers may impact their long-term lean-season flows, with adverse impacts on the economy owing to water shortfall and availability, and consequent fall in power generation from hydro-electric projects.

Changes in key climate variables, comprising temperature, precipitation, and humidity, may have significant long-term implications for the quality and quantity of water that these rivers receive from glaciers. Due to sea level rise, the fresh water sources near the coastal regions will suffer salt intrusion.[8,15]

PERCEIVABLE IMPACTS OF CLIMATE CHANGE WITH SPECIAL REFERENCE TO INDIA

The fine balance of the global ecosystems is likely to be disturbed in the future due to abrupt climatic changes which could happen in the form of floods, droughts, wildfires, severe cyclones, ocean acidification and so on. This would cause damages to biodiversity, and earth's built in capacity for repair and regeneration. The rise in temperature, change in precipitation patterns, sea levels rise, soil moisture loss, melting of snow cover of mountains and glaciers, coastal erosion and occurrence of damage to human lives are perceived as the visible impacts of climate change.[5]

Effects on Agricultural Crops

The major effect of climate change, particularly the temperature increase on a given crop is likely to be on shortening of crop duration, or its life cycle. Increase in temperature will speed-up crop maturity. In annual crops, the shortening of crop duration may vary from 2–3 weeks, thus, adversely impacting productivity. Another direct effect of temperature increase on crops like rice, wheat, sunflower and other such crops will be on their reproduction, pollination and fertilization processes. The indirect influences operate through changes in water availability due to inadequate or excess rainfall, and effect of increase in temperatures on pest and disease incidence frequencies. Modelling studies have indicated that changing climate will decrease yields in major crops like wheat, rice and maize. On the other hand, the impacts could be neutral to positive in groundnut, soybean and chickpea.[6,24]

Further, the impact of climate change on agricultural crops depends on a complex interplay between the effects of rising temperature, increased CO_2 concentrations and variations in rainfall. Other more complex effects may arise due to changes in other variables, such as the number of cloud-cover days. It is known that for both rice and wheat, a 2°C rise in temperature could lower yields by 15–17%. Increasing temperatures would affect rabi (winter planted crops) season production more seriously than kharif (summer planted crops) season production. The effects of rising temperature, however, may be offset by the effects of increased atmospheric CO_2 concentrations. Simulation studies suggest that, in general, climate change in various scenarios of CO_2 concentration and temperature rise would result in a small increase in rice yields. They further suggest that the corresponding impact on wheat is more variable, ranging from negative to positive.[8,25]

According to an earlier study done by Indian Agricultural Institute (IARI), increases in temperatures of up to 2ºC reduced potential grain yields in most places. Regions with higher potential productivity, such as agricultural areas in northern India were relatively less impacted by climate change than areas with lower potential productivity. Further, the study predicted that climate change would lead to boundary changes in areas suitable for growing certain crops. This means the potential areas for growing important food grains crop such as winter irrigated wheat may shrink.[25]

The study revealed that reductions in yields as a result of climate change were forecast to be more pronounced for rainfed crops as there would be no coping mechanisms to handle shortage of water for crops on account of rainfall variability. In nut shell, the study found that in sub-tropical environments the decrease in potential wheat yields ranged from 1.5–5.8%, while in tropical areas the decrease was relatively higher, suggesting that warmer regions could expect greater crop losses due to climate change.[25]

For rice production, an increase in temperature between 2°C–4°C is forecast to bring in reduction in yields. The impact of climate change would be more pronounced in eastern regions of India owing to increased temperatures and decreased radiation, resulting in relatively fewer grains and shorter grain filling durations. On the other hand, potential reductions in yields due to increased temperatures in northern India are expected to be offset by higher radiation, lessening the impacts of climate change. Although additional CO_2 levels in atmosphere may benefit crops, this effect would be nullified by increased temperatures.[25]

Effects on Crop Yields

Increase in ambient CO_2 concentration in atmosphere is expected to be beneficial since it leads to increased photosynthesis in several crops, including in wheat and rice. In spite of it, yields of major cereals crops, especially wheat are likely to be reduced due to reduction in grain filling duration, coupled with decreased fertilizer use efficiency, faster nutrient mineralization of soils, increased evapo-transpiration rates, spread of pest populations, owing to rise in temperatures which will be accompanied by reduction in rainfall/irrigation water supplies due to climate change.[3,6]

According to study conducted in Punjab, grain yield of rice would reduce by 5.4%, 7.4% and 25.1% for corresponding temperature increases of 1°C, 2°C and 3°C respectively, with all other climatic variables remaining constant. At times, a change in the minimum temperature is more significant factor than a change in the maximum temperature. At times, a change in the minimum temperature is more significant factor than a change in the maximum temperature. Grain yield of rice, for example, declined by 10% for each 1°C increase in the growing season minimum temperature above 32°C. Similarly, water shortage due to climate change would result in about 20% net decline in the rice yields in India.[6,26]

Historical Trends in Yields of Food Crops in India

Based on secondary data collected from Department of Economics and Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, GOI, and Economic Survey 2014–15, GOI, and its previous issues and Reserve Bank of India Statistics on Indian Economy, average yields data between 1960–61 and 2013–14 have been computed/used for studying the general trends in yields of some important food grain and commercial crops that are cultivated for human consumption in India.

The first of the two graphs provide graphical representations of yields of food grain crops with respect to wheat, and rice besides coarse cereals, which include maize, sorghum and other major and minor millets under this category. With some exceptions, the coarse cereals are cultivated generally in semi-arid regions of India. Yields of all food grain crops are showing increasing trend since 1960–61, especially wheat and rice that are cultivated under irrigated conditions/states/regions of India with farmers using all the available modern inputs while the Government provides timely farm extension services and price support mechanisms for their procurement.

The procured quantities go to the central pool in order to use them as buffer stocks, and release them during particular time of the year to soften prices in the market besides utilizing them for public distribution to benefit people in low income categories.[27]

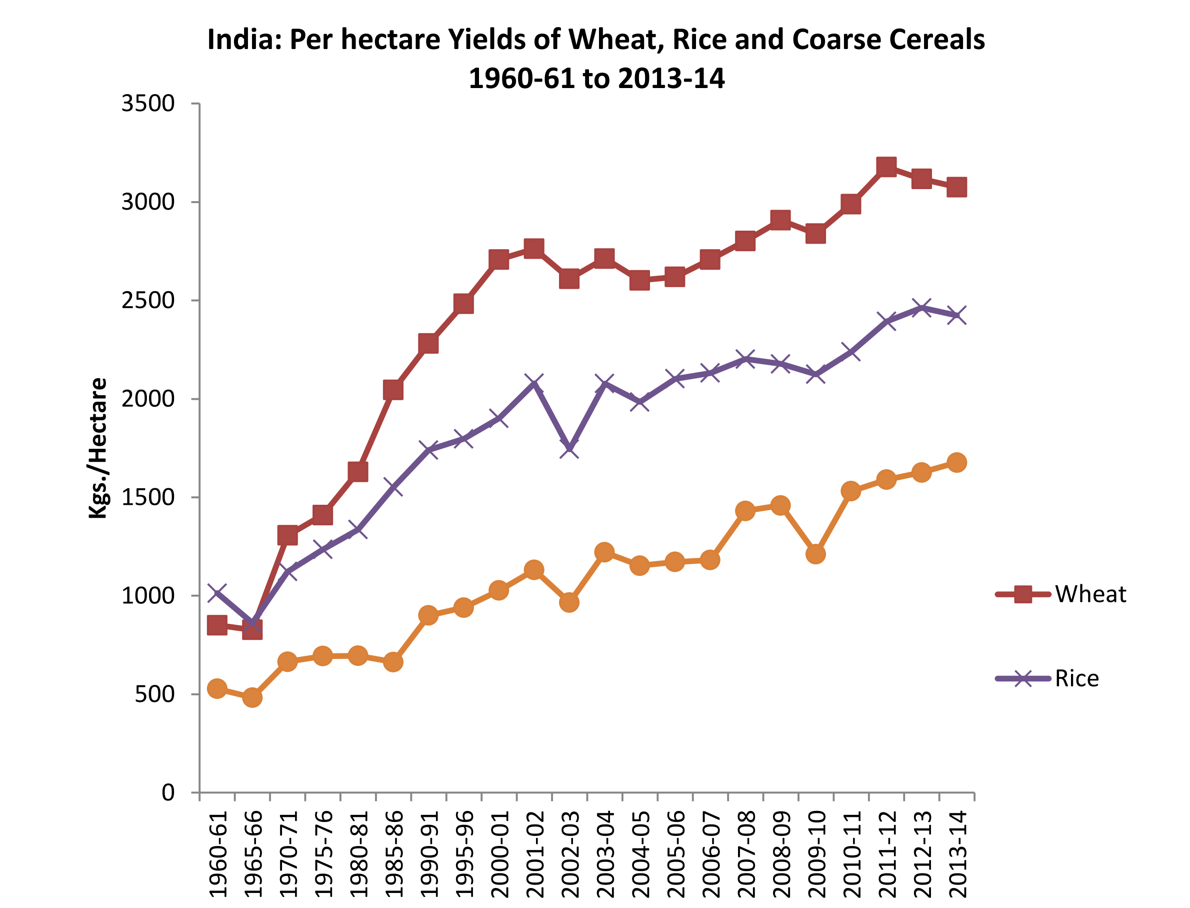

Fig.4. *India: Per Hectare Yields of Wheat, Rice and Coarse Cereals 1960–61 to 2013–14.*

It can however be observed that yields of both wheat and rice appear to be slightly lower than 2012–13 levels, while yields of coarse cereals are somewhat increasing. The explanations can be correlated partially with discussion above with regard to the effect of climate change on agricultural crops. The drought like situations either due to the absence, or insufficiency of south-west monsoon rains usually affects rainfed cropping areas more than the irrigated areas.

From the second graph, it can be observed that there are sharp fluctuations in yields of groundnut(peanut)crop, followed by soybean crop which also shows year to year fluctuations in yields since its commercial cultivation which began in 1970–71, but degree of fluctuations is slightly less than groundnut crop. The long-term trend shows that yields have increased for all three oilseed crops, including rapeseed and mustard, except for the fact that yields have declined for soybeans in the last 1–2 years. Sharp fluctuations in yields are due to irrigated cultivation vs. unirrigated cultivation for groundnut crop, where the planting and yields are influenced by the progress and performance of south-west monsoon each year. Monsoon progress also affects soybean crop which is also grown as rainfed crop generally but it is also affected by market prices and demand for its oil and oilcakes. At times, heavy rains have damaged this crop. Rapeseed and mustard are cultivated generally in irrigated and cooler parts of north and north-western India. Therefore, fluctuations are relatively mild unless, low moisture conditions in soil affect the crop due to insufficient monsoon rains in the preceding months/season.

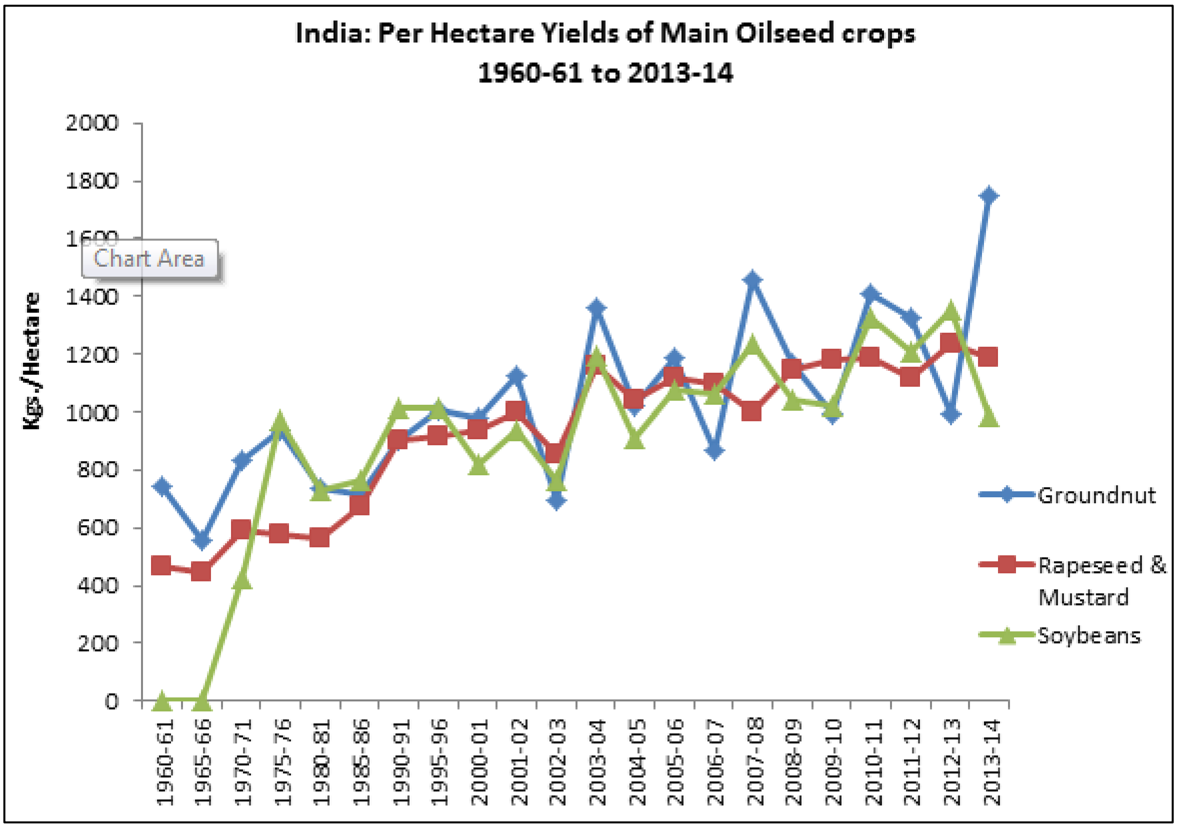

Fig.5. *India: Per Hectare Yields of Main Oilseed Crops 1960–61 to 2013–14.*

Impact on Dryland Agriculture

Rainfed agriculture in the semi-arid tropics is particularly vulnerable to climate change. Rainfed agriculture as a whole accounts for about 55% of net sown area, out of a total of 142 million hectares. Based on the available estimates, rainfed agriculture in the semi-arid tropic States comprising Andhra Pradesh, Gujarat, Maharashtra, Karnataka, Rajasthan, Tamil Nadu and Madhya Pradesh, accounted for 72.8 per cent of net sown area, whereas in the non-semi-arid tropics/states, it accounted for about 42.2 per cent of net sown area. Rainfed agriculture in the semi-arid tropics carries a much higher degree of risk, and is characterised by high variability in production, low yields and low returns. The semi-arid tropics are important to total agricultural production, gross cropped area and farmers' livelihoods in India, particularly with respect to the cultivation of minor millets, oilseeds and pulses.[3,9,28]

Impact on Groundwater Resources

Climate change is likely to affect ground water availability due to changes in precipitation and evapo-transpiration. As a result, recharging of groundwater resources such as wells, reservoirs, and bore wells will be affected. Rising sea levels may lead to increased saline water intrusion into coastal and island aquifers, while increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Demand for irrigation water for agriculture is likely to be more sensitive to climate change. A change in field-level climate may affect the requirement and timing of irrigation. Increased dryness may lead to higher demand for water, but demand could be reduced if soil moisture is found to be increased at critical times of the year. It is projected that India would require more water around 2025 and global net irrigation requirements would increase relative to the situation without climate change by 3.5–5% by 2025 and 6–8% by 2075.[3,29]

In India, roughly 52% of irrigation consumption across the country is extracted from groundwater; therefore, it can be an alarming situation with decline in groundwater resources and increase in irrigation requirements due to climate change. With more moisture in the warm air/atmosphere, rainfall and snowfall events would tend to be more intense, thus increasing the potential for floods. However, if there is little or no moisture in the soil to evaporate, the incident solar radiation goes into raising the temperature, which could contribute to longer and more severe droughts. Therefore, change in climate will affect the soil moisture, groundwater recharge and frequency of floods or drought episodes and finally groundwater level in different locations/regions.[3,29]

Impact on Dairy and Livestock Production

Heat stress has strong influence on dairy animal's performance owing to physiological changes in the normal functioning of their body systems. Sudden changes in temperature, either a rise in maximum temperature to more than 4°C above normal during summer i.e. heat wave or a fall in minimum temperature to below 3°C than normal during winter i.e. cold wave would result in a decline in milk yield of crossbred cattle and buffaloes. The estimated annual loss due to heat stress is currently estimated at about 2 million tons, in India. Global warming is likely to result in an additional loss of 1.6 million tons in milk production by 2020 and 15 million tonnes by 2050 from current levels. Northern India is likely to experience more negative impact of climate change on milk production (obtained from both cattle and buffaloes) due to rise in temperature during 2040–2069 and 2070–2099 climate change induced environment scenarios. Commercial poultry and other livestock are also susceptible to heat stress as it results in their reduced feed intake, which adversely affects egg laying performance (egg laying hens) and in decrease in body weight addition for broilers(meat production), and followed by increased levels of mortality upon increase in temperatures.[3,6,24]

Positive Effects of Climate Change on Agricultural Crops

Increase in CO_2 concentration has been shown to increase crop growth, dry matter production and yields in some regions; however, this effect is dependent upon degree of water stress, soil nutrients status, and changes in temperature or rainfall conditions.

In experimental conditions, most crops grown under enriched CO2 environment showed increased growth and yield due to enhanced photosynthesis and water use efficiency (WUE).[23] If the direct effect of CO_2 is included, yields are projected to increase for rainfed crops under both the A2 and B2 emissions scenarios in the 2080s. The increase is projected to be highest for rainfed maize under the A2 scenario, as higher CO_2 concentration would boost yields of rainfed maize crop in the country Simulated yield of winter maize showed an increase in the range of 8.4–18.2%, 14.1–25.4% and 23.6–76.7% for years 2020, 2050 and 2080 scenarios respectively. Maize crop grown under increased CO_2 levels and increasing temperature demonstrated a reduction in crop duration and maturity days from the baseline levels, which was accompanied by an increase in grain weight, grain number and total dry matter production, for all these three scenarios through 2080. Global climate change may increase production of potato in Punjab, Haryana and western and central Uttar Pradesh by 3.46–7.11% in A1b 2030 scenario, but it would decline by 4–16% in West Bengal, and in some parts of southern India. The simulation results indicate that on an average, future climate would have a positive impact on productivity of rainfed soybean in the country. Soybean yields under different future climate scenarios such as in 2030 and 2080 are projected to increase in the range of 8–13%. In case of groundnut (peanuts) crop, excepting the climate scenario of A1B 2080, which demonstrated a decline of 5% in yield, the remaining scenarios indicated 4–7% increase in rainfed groundnut crop yields vis-à-vis the baseline yield data. Simulation studies indicated positive effect of climate change on coconut yields in west coast and parts of Tamil Nadu and Karnataka and negative effects on nut yield in East-coast of India under some specific climate change scenarios in 2020, 2050 and 2080 scenarios.[6,24]

Other positive effects may include shift in the area of cultivation of some crops, which could create new economic and marketing zones to benefit people in these areas. This could be the case for some horticultural crops in temperate regions, where a shift in apple orchards from lower altitudes to higher altitudes has occurred in some areas. As a result, farmers in the lower elevations have taken up cultivation of fruit crops like pomegranate and kiwi besides taking up commercial vegetable and floriculture crops production with success. Similarly mango cultivation has also spread to areas with slightly lower temperature thereby making the fruit available for a longer period in the market. Other scenarios connected with climate change may include “protected” cultivation of horticultural crops. This could provide opportunities to young agriculturalists for producing climate-resilient quality products. This type of technology oriented production is expected to create job opportunities for the unemployed.[24,25]

STRATEGIES FOR HANDLING CLIMATE CHANGE

Mitigation measures would aim to reduce the emissions of greenhouse gases that cause climate change in the first place, e.g. by switching to renewable sources of energy such as solar energy or wind energy, or public sector investment in nuclear power plants instead of burning fossil fuel in thermal power stations. Further, emission of greenhouse gases from agricultural crops also have to be contained or reduced.[4,7,15]

Mitigation measures are critical to contain the damage and changing agricultural/ land use practices have a major role to play. According IPCC,[4] forestry, accounted for about 17% of CHG gas emissions in 2004. If reforestation is initiated, and at the same time de-forestation is halted, and existing forests are managed on more sustainable basis, soils can be managed to store carbon. Additionally, agro-forestry can also be utilized as a mitigation option. Although biofuels have potential to GHG gas emissions by replacing fossil fuels, their production have environmental costs, and their raw materials (sugarcane and maize/corn, besides sorghum to some extent) tend to compete for requirements of food and feed for human consumption. Research into biofuel production is required so that their production takes place in an environmentally sustainable way, which would also benefit small and marginal farmers. In addition to climate change, impacts of other global trends such as population growth, urbanization, increasing demands for water, food, feed and fiber, coupled with over-exploitation of ecosystems are also happening globally.[14,19,20]

The results of mitigation efforts to reduce emissions in order to slow down temperature rise will not be visible for decades, but these efforts will help developing countries' agriculture and natural resources management to accumulate development benefits. At this stage, whether we are making mitigation efforts or not, climate change is already happening, and temperatures will continue to rise during the coming years. The impacts of climate change will negatively will interact with, the other impacts caused by population growth, urbanization, increasing demands for water, over-exploitation of ecosystems, and shifts in world economics, and so on.[4,14]

Carbon Sequestration

In our agro-ecosystem, carbon is mainly held by cultivated crops and natural vegetation and in soil. Oceans and other aquatic bodies also stock large volumes of carbon, besides the atmosphere. As per US Environment and Protection Agency (USEPA) estimates made in 1995, soils contained about three times more Carbon than vegetation, all types, and twice as much as that was present in the atmosphere.[30] Thus, soils are the biggest reservoir of carbon. Additionally, fossil fuels e.g., coal, petroleum, and natural gas contain large amounts of carbon that are released upon their combustion, or use. Fixed carbon is a life of soil and also governs the capacity to provide the nutrients to plants. Carbon supports the existence of life on the earth. All ecosystems both store and emit carbon back to the atmosphere at lesser or greater extent as they continuously recycle carbon by photosynthesis and respiration.[13]

Soils can be a storehouse, or natural sink for atmospheric carbon dioxide (CO_2), it has been found that excessive tillage frees carbon from organic matter, and it is released into the atmosphere as CO_2. However, with the photosynthetic activity of crops and natural vegetation, CO_2 is converted into organic forms of carbon such as sugars, starch and cellulose. Thus soils and vegetation serve as a natural sink for carbon.

Mitigation of CO_2 emissions from agriculture can be managed by increasing carbon sequestration in soil through manipulation of soil moisture and temperature, besides setting aside surplus agricultural land under fallows, and restoration of soil carbon on degraded lands. Soil management practices such as reduced tillage, manuring, residue incorporation, improving soil biodiversity, micro aggregation, and mulching can play important roles in sequestering carbon in soil. Some technologies such as intermittent drying, site-specific Nitrogen management can be easily adopted by the farmers without additional investment.[6,13]

Adaptation Strategies to Climate Change

To handle and manage the impact of climate change, the adaptation strategies would include: developing crop varieties tolerant to heat stress, salinity and capable of withstanding floods and drought, besides modifying crop and water management practices, and adopting resource conserving technologies (RCTs). Additionally, farming sector would require crop diversification, improving pest management practices, and using weather forecasting information at micro level and providing crop insurance to farmers and making full use of traditional knowledge of farmers to handle climate change scenarios.[2,16,21]

In order to protect the sustainability of the rice-wheat and other cereals-based cropping systems, which are the backbone of food security in India, and in adjoining countries, Conservation Agriculture (CA) holds the key. The components of CA agriculture include: minimum mechanical soil disturbance like zero tillage (ZT), organic soil cover with crop residues recycling or cultivation/use of cover crops, and diversified, efficient and economical viable crop rotations. Further, laser assisted precision land levelling, direct drilling into the residues, and/or direct seeding of rice, brown manuring with Sesbania, un-puddled mechanical transplantation of rice, raised bed planting, crop diversification, and associated component technologies like site-specific nutrient management also come under CA based crop management technologies.[6]

These technologies are being adopted by farmers in the rice-wheat belt of the Indo-Gangetic Plains (IGP) of India because of the advantages in terms of saving of labour, water, fuel, and cost along with timeliness in operations/practices, particularly for early planting of wheat. These technologies have pronounced effects in rice -wheat system on mitigation of GHG emissions and adaptation to climate change. It has been shown that global warming potential (GWP) is reduced in direct drill seeded rice and wheat on beds or with ZT compared to the conventionally puddle transplanted rice and tilled wheat.[6]

To minimize the adverse impacts of climate change on human/rural populations, the vulnerable communities can be relocated or shifted from the vicinity of coastal areas to interior areas in order to stay away from rising sea levels. If they happen to be from farming communities facing adverse impacts of climate change, they should select and cultivate those crops, or varieties that can withstand higher temperatures, or excess rainfall for short durations in agricultural areas that would often face fluctuating weather conditions.[4,5,15]

Why it is important for India

Agriculture is the source of livelihood for nearly two-thirds of the population in India. The sector currently accounts for 14.2% of the GDP and employs 55% of country's total workforce. The year to year variations in agricultural growth are mainly due to the performance of monsoon. Some part of the country or the other experiences monsoon failure almost every year with many states experiencing drought once in 2–4 years. The south-west monsoon account for nearly 70–75% of the natural precipitation received annually, and significantly affects kharif (summer planted crops) food grains production, agricultural GDP, farmers' income and price stability in the country. Both the amount of rainfall and its distribution pattern are crucial factors that determine the performance of agriculture. The probability of monsoon rains being erratic is 40% of the time which means that in 4 out of 10 years there would be an adverse impact on food grains production, if the appropriate strategies to deal with such situations are not there with the Indian government.[31] Monsoon failures result in droughts which have serious implications for small and marginal farmers, and livelihoods of the rural poor. The impact of climate change on agriculture will be one of the major factors influencing food security of–India in coming decades. A major part of the agriculture in India is rainfed, and will remain so for a foreseeable future. The crop losses due to climate variability will vary from region to region depending on regional climate, cropping systems, soils and management practices. Rainfed crops are likely to be hit by climate change because of the limited options available with small farmers to cope up with variations in rainfall and temperature changes.[3,9,30]

National Initiative on Climate Resilient Agriculture (NICRA)

In February, 2011, Indian Council of Agricultural Research (ICAR) launched a National Initiative on Climate Resilient Agriculture (NICRA). It is a network project that aims to enhance resilience of

Indian agriculture to climate change by undertaking strategic research projects and holding demonstrations of the improved production and risk management technologies for the benefit of farmers. The research on adaptation and mitigation covers crops, livestock, fisheries and natural resource management.[3,24]

How it Works

The technology demonstration component of NICRA works across network centres of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) by identifying climatic vulnerabilities of agriculture in the selected village. For this purpose, historical weather data is collected along with information on farmers' experiences and perceptions to develop and implement adaptation and mitigation strategies. The focus of the program is not only to demonstrate the climate resilient agriculture technologies but also to institutionalize mechanisms at the village level for implementation of successful adaptation strategies on a sustainable basis.[30]

The information on damage to crops, dairy and livestock, and associated infrastructure from extreme events is also collected for past three decades. To understand the farming systems, information on resources, constraints and climatic vulnerabilities, opportunities available to climate change adaptation and mitigation in the selected village is collected from farmers and knowledgeable people in the village.

Besides, information on land use pattern, area, production and productivity of different agricultural and horticultural crops, livestock composition and production, fisheries production, awareness level of farmers about climate change, ground water level and its use, income from agriculture and allied activities, level of risk of crop loss due to climatic variability in the past one decade is also collected from farmers and key knowledge providers in the villages.[30]

During participatory appraisal, the overall status with respect to natural resources-land, soil, water, socio-economic, institutional and infrastructural facilities, and major farming systems is assessed. Information on land holding structure, literacy levels of farmers, their assets, participation in social networks, people below poverty line, access to critical inputs, marketing opportunity for selling farm outputs, access to market information and technical knowledge, skills of farmers, sources of irrigation/water, access to different government schemes, existing institutional arrangements, commodity groups, and their effectiveness, are also assessed.

The major interventions are implemented-both under "on-farm and on-experimental/demonstration station situations", and are grouped under four theme areas.[30]

To demonstrate contingency plan related to crop, variety, crop management practices during weather fluctuations on a real time basis. Under this theme, alternate crop or cultivar choices can be made in tune with the actual rainfall situation and soils in a given location.[30]

Demonstration of efficient moisture conservation practices, rainwater harvesting or enhancing water use efficiency (e.g. sprinkler irrigation) as adaptation and mitigation strategies; groundwater recharging through bore well for open well, and defunct well.[30]

Introduction of modern machines /implements to create awareness for their use for different crops by establishing custom hiring centres in the village; to help in timely sowing and harvesting of rainfed crops.[30] To develop alternate land use system/farming system for carbon sequestration and ecosystem services.[30]

National Mission on Sustainable Agriculture.[9]

The National Mission for Sustainable Agriculture (NMSA), which is one of the eight Missions under the National Action Plan on Climate Change,[9] which seeks to address issues regarding 'Sustainable Agriculture' in the context of risks associated with climate change by devising appropriate adaptation and mitigation strategies for ensuring food security, equitable access to food resources, enhancing livelihood opportunities and contributing to economic stability at the national level. Due to agriculture's significant share in GDP and exports besides employing around 500-600 million people directly or indirectly, agriculture is vital to India's economy and the livelihood of its people. Overall, the following strategies, or interventions have been proposed.

Requirement for Improved seeds, Livestock and Fish Cultures

Biotechnology should be used to develop futuristic genetic pool/resources having greater adaptive capacity to cope up with changing environments to overcome vulnerabilities arising out of climate change. The rich indigenous genetic resources should be conserved for future use in developing climate resilient crops, dairy animals and fisheries. Public private partnerships should be promoted in development, management and dissemination of the improved varieties to farmers to sustain productivity, on continuous basis with focus on research and development of resilient genotypes.[8,9,16]

Water Use Efficiency

Since around two-thirds of the cultivated land in India is rainfed, effective management of available water, increasing water use efficiency and additional sustainable sources of water need to be developed. Strategies under this dimension would include the application of a range of technologies coupled with demand and supply side management solutions to enhance water use efficiency for irrigation. While some technologies can be implemented in the short term, there are other emerging areas like recharging of aquifers, conjunctive use of surface and ground water, and controlled extractions, which would require collaboration and capacity building for technology absorption before being put into sustainable use. The role of local institutions in managing water allocation and utilization will also be crucial for promoting efficiency. Drip irrigation systems, water harvesting and flexible water storage systems comprising tanks, small ponds, groundwater sources and reservoirs are expected to play an increasing role in meeting water requirements for agriculture in future.[9,14]

Improved Farm Practices

Improved agronomic practices have the potential to help reduce farm level losses through improved soil treatment, increased water use efficiency, judicious use of chemicals, labour and energy, besides increased soil carbon storage capacity of soils. Development or use of resource conserving technologies and equipment offer new opportunities for better livelihoods for the resource poor, small and marginal farmers.[9, 16]

Nutrient Management

Management of crop nutrients to enhance crop productivity is a major technological challenge for ensuring food security to meet the demand for food and raw materials. To ensure soil health, accurate information/data on soil resources is an important requirement. Soil health can be improved through several site and soil-specific management options, which includes balancing the nutrient dose usage relative to nutrients present in soils. This way nutrient use efficiency of crops can be improved.[9]

Agricultural Insurance

Agricultural insurance is an important mechanism by which risks to agricultural output and income can be addressed. Crop insurance gives incentives to farmers to adopt innovative options by spreading the risks over time. It also stabilizes farm incomes thereby enabling farmers to repay debts.[6,9,18]

Credit Support

Timely credit availability and disbursement to farmers is essential for sustaining farm productivity. Institutional support of credit to farmers can help in adoption of improved management practices including resource conservation technologies, diversification of crops, addition of post-harvest value addition facilities, which are all aimed to reduce risks and enhancing farm incomes. Flow of credit to agriculture, should be multi-channel to involve input dealers, final product/commodity processors/end-user companies, NGOs, and other such Institutions to help small and marginal farmers to manage the additional risks from climate change in a sustainable manner.[9,18]

Markets

Insufficient marketing infrastructure, non-availability of proper market information, and deficient storage facilities results in huge post-harvest losses in the food supply chain. Some of the major initiatives that are to be taken up under this dimension include, reducing quantitative as well as qualitative losses across the supply chain; creating market aligned production systems; strengthening climate resilient post-harvest management, storage and marketing and distribution system; strengthening timely access to quality inputs; strong farmer institution-industry interface; and encouraging food processing industries to purchase farmers' outputs for making value-added products.[9,18]

Therefore, investment in the physical infrastructure that facilitates food producers to be connected to markets in large urban markets is critical for food system resilience and food security. Investments are needed to improve the transportation, storage and marketing infrastructure in order to withstand the risk of disruption of supply networks due to extreme events.[18]

Use of Communication and Information

Effective communication pertaining to various aspects of farming, for example availability of new production technologies, management practices, and marketing information, besides weather forecasts at local and regional level are critical to help farmers adapt to climate change situations in near to long-term. Communication is also important for carrying laboratory generated technologies to commercial fields to improve farm productivity, and prepare farmers for climate adaptability. Another important aspect is to use traditional knowledge of farmers to handle climate change.[6,9,18]

Modern extension services should be based on different funding models that could involve the public, private and civil society sectors, to face the food security challenges from climate change. To ensure that productivity and resilience enhancing agro-technologies are adopted by farmers, extension programs and workers should target decision making individuals in farmer families, and in their villages.[18]

International cooperation between governments on adaptation and mitigation strategies, and best practices, as well as on technology transfer, is essential to address the impacts of climate change on food security. Learning from the experiences of successful national programs of other nations that can work regionally can help partner countries to develop their own programs. Also, lessons learnt in one region of a country might be useful for other regions in the same country in future. Institutions that can transfer learning process internationally and regionally will be required to take the lead in this direction.[18]

Livelihood Diversification

Livelihood diversification provides options of supplementing farmer family income from either on-farm agricultural, or off-farm activities, thus mitigating risks by providing additional support to agricultural income under conditions of non-climatic and climatic stresses, and from alternate livelihood options. The strategies under this dimension would include diversification of agriculture into other high-value crops, dairy, livestock & poultry, and horticultural crops, sericulture, agro-forestry, crop-fish farming combinations and so on.[9]

CONCLUSIONS AND RECOMMENDATIONS

India should invest in research and development (R&D) activities for developing high-yielding new generation of climate change adaptable crops, with improved crop management practices. These crops should have better nutrient utilization rates from soil, and score over existing varieties in terms of water use efficiencies. Additionally, alternate cropping systems should be tried to prevent risks of crop failures, devise efficient sources of energy, and install decision support systems (DSS) at village level to put in place mitigation strategies to handle vulnerable situations arising out of not too distant climate change. To lessen the accumulation of GHG gases, agro-forestry could be taken up as a mitigation measure.

The new varieties should be resilient to drought, heat and submergence situations. The seeds and planting materials should be made in large volumes to make it available to farmers by fostering public-private sector partnerships. Crop planting dates should be changed to avoid heat stress or cyclones at maturity stage. In this context, crop maturities may have to be relatively smaller.

Extension scientists and field staff should encourage farmers to adopt location-specific conservation techniques, which should include cover cropping, moisture conservation, rainwater harvesting, groundwater recharge, locally adapted cropping systems for water efficient agriculture and demonstrate such technologies to farmers' if possible on their fields.

Policy implementation staff of the State Governments should ensure that vulnerable strata of the rural/agricultural society get access to National Government declared support/relief programs connected with food security, agricultural and enterprise subsidies, rural finances, poverty reduction programs, technology adoption support and so on.

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