Climate Change and Agriculture in India

Edited by

Akhilesh Gupta and H. Pathak

सत्यमेव जयते

Climate Change Programme
Strategic Programmes
Large Initiatives and Coordinated Action Enabler (SPLICE) Division
Department of Science & Technology, Ministry of Science & Technology
Government of India, New Delhi

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A Thematic Report of
National Mission on Strategic Knowledge for Climate Change (NMSKCC)
under National Action Plan on Climate Change (NAPCC)

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January, 2016

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Dated: January 13, 2016

Foreword

Climate is the most important determinant of crop productivity, particularly in country like India, where about 2/3rd of the cultivated area is rainfed. Climate change, therefore, is of serious concern having large-scale impacts, directly and indirectly, on agriculture. It is manifested with increase in global temperature, increased intensity of rainfall, rising sea level, melting of glaciers, shifting of crop growing season and frequent occurrences of extreme events such as drought and flood.

To address the long-term negative impacts of climate change and short- and medium-term impacts of climatic variability on agriculture, there is a need for sustained research on increased adaptation and mitigation, capacity building, development activities, and bringing necessary changes in policies. These actions have to be accompanied by long-term sustained actions towards generation and strengthening of strategic knowledge system in key impact sectors like water, agriculture, energy, health, etc. by building human and institutional capacity. The National Mission on Strategic Knowledge for Climate Change (NMSKCC) was initiated with this very objective.

The mission had identified various thematic areas and professional expert groups in India in some scientific institutions for commissioning thematic and policy research programmes and activities. The current report is on the thematic area of 'Agriculture' contributed by three research groups in lead institutions like, Tamil Nadu Agricultural University, Coimbatore; International Crops Research Institute for the Semi-Arid Tropics, Hyderabad and ICAR-Indian Agricultural Research Institute, New Delhi.

I am pleased to see that a thematic Report on "Climate Change and Agriculture in India" has been brought out by Climate Change Programme of SPLICE Division of DST based on the inputs received from these groups. We gratefully acknowledge contributions of Dr. H. Pathak, Principal Scientist and Professor, ICAR-Indian Agricultural Research Institute, New Delhi; Dr. V. Geethalakshmi, Professor, TNAU and Dr. Mamta Sharma, ICRISAT, Hyderabad in the preparation of this report. I am particularly grateful to Dr. Akhilesh Gupta, Head, SPLICE, DST and Dr. H. Pathak for editing the report.

I am confident that the report will be of great use to the students, researchers and policy makers engaged in the area of climate change impact on agriculture.

(Ashutosh Sharma)

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Preface

Agriculture is a cause of climate change and also suffers from the consequences. Major adverse impacts of climate change on agriculture are owing to increase in temperature; change in rainfall pattern; weather hazards, decline in soil and water quality; shifting dynamics of insects, diseases, soil flora and fauna; intrusion of sea water on land and biotic and abiotic stresses arising due to climatic extremes. There could be a few positive impacts of climate change on agriculture in some locations because of change in temperature and moisture regimes.

To address the consequences of climate change we need to develop adaption and mitigation options. There is an urgent need for creating an infrastructure both in terms of human resource and state of art physical facilities for collecting, collating and updating climatic data, essential pre-requisite for modeling and forecasting the impact of impending climate change on agriculture. The strategies have to be built upon the current knowledge about climatic, ecological and economic systems' dynamics.

Under the National Action Plan on Climate Change (NAPCC), the Government of India has launched eight National Missions during the XII Five Year Plan. The National Mission on Strategic Knowledge for Climate Change (NMSKCC), implemented by the Department of Science and Technology (DST), is targeted to enable the country to cope up with the impacts of a changing climate. Under this programme, the DST has supported Tamil Nadu Agricultural University (TNAU), Coimbatore; International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, Telangana and ICAR-Indian Agricultural Research Institute, New Delhi to undertake research on the impact of climate change on agriculture for developing appropriate strategic knowledge for climate change adaptation and mitigation. The report summarizes the salient findings of the project and identifies the strategic knowledge that was generated to combat the adverse impacts of climate change on Indian agriculture.

One of the editors (AG) is grateful to Prof. Ashutosh Sharma, Secretary, DST for encouragement and motivation. Thanks are due to Dr. (Mrs) Nisha Mendiratta, Scientist-F, Dr. Anand Kamavisdar, Scientist-E and other colleagues in CCP, SPLICE Division of DST for their support. We are thankful to all contributors of the report for their valuable inputs in the preparation of the manuscript.

We sincerely hope that the publication will be of great use to scientists, researchers and policy makers engaged in the field of climate change and agricultural research and development.

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Content

Executive Summary

Agriculture is crucial for ensuring food, nutrition and livelihood securities for India and it engages almost two-third of the workforce in gainful employment. 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 the past years, Indian agriculture had made a significant progress, but currently it faces many challenges. Stagnation of net sown area, plateauing yield level, deterioration of soil quality, reduction in per capita land availability and the adverse effect of climate change are the major challenges to Indian agriculture. Moreover, 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 biotic and abiotic stresses arising from climatic variability and climate change. More than 80% of Indian farmers are marginal farmers, having cultivable land of less than one hectare or small farmers with cultivable land area of one to two hectares, with poor coping capacity. Additionally, the Indian farmers are heterogeneous and unorganized in nature. Climate change and its variability are likely to aggravate the problem of future food security by putting pressure on agriculture affecting its sustainability.

Under the National Action Plan on Climate Change (NAPCC), the Government of India has launched eight National Missions during the XII Five year plan. The National Mission for Sustainable Agriculture (NMSA) and the Mission on Strategic Knowledge on Climate Change (NMSKCC) are targeted to achieve an agricultural growth rate of 4% per annum and also enable the country to cope with the impacts of a changing climate. Under the NMSKCC, the DST has supported Tamil Nadu Agricultural University (TNAU), Coimbatore; International Crop Research Institute on Semi-Arid Tropics (ICRSAT), Hyderabad and ICAR-Indian Agricultural Research Institute (IARI), New Delhi to undertake research on the impact of climate change on agriculture for developing appropriate adaptation strategies including strategic knowledge. The results derived from these studies are summarized in the report.

The TNAU worked on ‘Assessing Impacts and Developing Adaptation Strategies for Agriculture in Tamil Nadu’ to assess the impact of climate change on agriculture at river basin scale in Tamil Nadu. The climate-related risks in river basins were ranked based on the likelihood, probability of occurrence and their consequences on crop production. It documented the current knowledge of farmers on climate change, non-climatic stress and sensitivities that aggravate the issues as well as existing local adaptive capacities of the farmers. Future climate data were generated for Tamil Nadu region using Special Report on Emission Scenarios (SRES). It analyzed the influence of the global climate drivers (ENSO/IOD) on rainfall of Tamil Nadu and its impact on hydrology and crops productivity at river basin scale. Strong El-Nino years (SOI between -10 and -35), had a positive correlation with Southwest rainfall in the eastern and northeastern parts of Tamil Nadu. As far as NEM is concerned, only southern Tamil Nadu showed correlation upto 0.4 with El-Nino condition, while all other parts had weak correlation. The mean rice productivity was shifted to up in El Niño and normal years indicating the possibility of getting more rice yields with less crop production risk compared to La Niña years. Future climate predictions derived from the ensemble of 16 GCMs for Cauvery basin indicated the increase in rainfall ranges between 7 and 21% towards mid-century (2040-2069) while this increase is projected to be between 10 and 33% in end century (2070-2099) compared to baseline (1971-2005). Temperature is expected to increase by 1.5 to 2 °C and 3 to 4.5 °C) in the mid and end century time scale. The project calibrated and validated the impact models such as SWAT, DSSAT and APSIM for their application in Tamil Nadu conditions. SWAT model predictions indicated that annual Potential Evapotranspiration (PET) for Cauvery basin would vary from 3 to 4.5% and 8.4 to 9.3% for the mid and end century scenario respectively. Annual water yield is expected to increase by 14 to 21% during mid-century and is projected to increase further by to 14% and 7 to 18% in the mid and end century, respectively. It quantified the response of rice and maize crops to elevated temperature and CO_2 using the state of art controlled environmental facilities such as climate control chambers and SPAR system. Increase in temperature with or without CO_2 enrichment affected the phenology and productivity of C_3 and C_4 plants with different magnitude. Temperature increase alone has negatively affected the C_3 crop (rice) more compared to C_4 crop (maize). However, CO_2 enrichment had compensated the negative impact of elevated temperature to certain extent. The project assessed the impact of climate change on crop water requirement, growth and productivity of crops through integrated modeling approach and identified adaptation options such as screening temperature tolerant cultivars, identification of best sowing window, use of nano-fertilizers, altering the cultivation method (SRI), etc., to reduce climate change impact. NH_4^+–N loaded nano-zeolite application enhanced nitrogen availability, crop growth in addition to minimizing the emission of methane from rice soils.

The project on 'Excellence on Climate Change Research for Plant Protection', implemented by ICRISAT, Hyderabad focused on effect of climate change on disease and insect-pest problems of two most important legumes -chickpea and pigeonpea under rainfed conditions in India. The primary aim of this project was to understand the effects of climate change on the relative abundance and diversity of insect-pests and pathogens across geographical regions, pest × host plant × environment interactions, and then influence on insect-pest and diseases incidence and extent of losses due to biotic stress. The major outcome of this project is the development of methodologies that will be required to quantify the information on emerging pest problems, their geographical distribution, and severity and damage, effect of climatic changes on expression of resistance to insect-pests and pathogens, select varieties that are resistant to diseases and insect-pests across environments, and reduce pesticide application for a safer environment. The information on pest × host × environment interactions will be useful to scientists in India, who can use the standardized techniques for phenotyping for pest resistance to identify and develop pest resistant cultivars for genetic management of emerging and anticipated diseases and insect-pest problems in India. The information will be useful to research planners, policy makers, scientists, and farmers for sustainable crop protection in India. The outcome of this project will have a major bearing on pest mitigation strategies in an environment friendly manner for sustainable production of grain legumes and increasing food security in dry land areas – particularly the regions, which are most vulnerable to climate change.

The project on 'Adaptation of Indian Agriculture to Climate Change', implemented by Indian Agricultural Research Institute (IARI), New Delhi focused on developing adaptation technologies to enhance the resilience of agriculture to the current and future climatic risks and updating simulation models for assessing impact of climate change and adaptation strategies. Existing knowledge on climate change adaptation available in various institutes and universities in the country was collated and analyzed. This will help in developing strategic knowledge for climate change adaptation and can be implemented by the farmers. Methodology for prioritizing the adaptation strategies in terms of their importance, urgency, no-regret characteristics, co-benefits and mitigation effect. Growth and yield response of wheat, rice and maize cultivars to heat and moisture stresses was assessed and tolerant cultivars were identified. Phenotyping and physiological evaluation of genetic populations and germplasm resources for drought and heat stress tolerance in wheat was carried out. A core set of genetic resources (including drought-adapted cultivars, advance lines, elite landraces, was evaluated under irrigated and rainfed conditions. Conservation agriculture practices such as direct seeded rice (DSR) with or without Sesbania brown manuring, rice residues mulch in wheat and summer mungbean grown for grains and stover incorporated as green manure have been evaluated for adaptation to climate change. Differential protein profiling of wheat pollen was carried out using 2-DE under ascorbic acid and heat stress. The Info Crop simulation model was upgraded and the InfoCrop version 2 was released. Using this model, a simulation analysis was done to assess the impacts of climate change (MIROC and PRECIS scenarios) on rice, wheat, mustard and potato crops in the IGP region. The adaptation gains and vulnerable regions also are derived. Climate change is projected to decrease the wheat yield in the range of 8-24% by 2050 in IGP. Future temperatures may constrain higher productivity of irrigated rice in Punjab, Haryana and Rajasthan. In case of mustard, though yield may improve in Punjab and Haryana but in Uttar Pradesh, Bihar and Assam they are projected to reduce up to 6%. The potato crop duration in the IGP is projected to decrease due to climate change. Climate change is projected to reduce potato yields by ~2.5, ~6 and ~11% in the IGP region in 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099) time periods. Adaptation analysis indicated that negative impacts can be overcome and substantial increase in yield can be realized by timely sowing and better management of improved varieties of wheat (~11%), rice (17-20%), mustard (~25%%) and potato (~8%). The results indicate that the negative impacts of climate change can be offset with either agronomical management or with improved varieties in shorter periods (the 2020 scenario); but in the longer periods (2050 and 2080 scenarios), growing improved varieties, coupled with efficient crop management, will become essential to enhance productivity for meeting increased demand. A web-enabled crop growth monitoring system was developed and hosted on public website http://creams.iari.res.in. Impacts of elevated CO_2 (570 ±25 ppm) on population of brown plant hopper was evaluated and a forecasting system for spot blotch in wheat was developed and validated. Forecasting system for spot blotch (most damaging disease in wheat) has been validated for first appearance of spots on leaves to facilitate exact timing of fungicide application. Strategic knowledge for climate change adaptation and mitigation in agriculture has been generated and a road map has been suggested for its implementation.

It is felt that there exist knowledge gaps to address the climate change challenges and the future research need to be focused on that line. For example, there is a need to predict the future climate at finer resolution with low uncertainty for reliable impact assessment. Concerted efforts are required for development of mitigation and adaptation strategies to climate change so as to increase resilience and reduce vulnerability of Indian agriculture at local, regional and national scales. As climate change impacts has no boundaries, research collaboration between developed and developing countries with funding support should be promoted and strengthened for developing and transferring climate-smart technologies. Development and operationalization of adaptation strategy necessitate socio-psychological empowerment of farmers besides developing competencies in acquiring knowledge and skills related to adaptation practices.

To face the challenges of food security and climate change, the country needs to reorient its land use and agriculture with the state-of-the-art technologies and policy initiatives. Impact of climate change on gender is another area that needs to be concentrated. Cost on adaptation and economics need to be worked out for the future climate under business as usual condition and for changed management situation for up-scaling adaptation options to larger regions. 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.

The report is structured in following sections: First section introduces the sensitivity of agriculture to changing climatic conditions with special reference to Indian sub-continent. Second section deals with climate change in global and Indian context. Third section indicates the Impact of climate change on Agriculture in India and also deals with the climate change assessment and projection. Fourth section describes the adaptation of Indian agriculture to climate change. Fifth section narrates the state of art research done on the impact of climate change on agriculture and hydrology. Sixth section narrates the initiatives of govt. of India for climate change adaptation in agriculture. Seventh section discusses the Research initiatives undertaken under National Mission on Strategic Knowledge for Climate Change (NMSKCC) as part of Climate Change programme (CCP) of the DST. This section explores the methodologies and new knowledge generated from the studies conducted by the partnering institutions and the potential technologies that would minimize GHG emission to support for increasing resilience against climate change in sustaining crop production.

1. Introduction

Agriculture is crucial for ensuring food, nutrition and livelihood securities for India. Indian agriculture had made a significant progress in the past, but currently it is facing many challenges. Stagnating net sown area, plateauing yield levels, deterioration of soil quality, reduction in per capita land availability and the adverse effect 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 biotic and abiotic 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 farmers are heterogeneous and unorganized. Climate change and variability are likely to aggravate the problem of future food security by putting pressure on agriculture affecting its sustainability.

The global climate change may lead to melting and/or diminishing glaciers, rise in sea level and increase in the concentration of greenhouse gases. However, the most prominent environmental issue 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 temperature, occurrence of hot days, hot nights and heat waves; increasing frequency of heavy precipitation events; increased snow melt and rise in sea level. The IPCC's Fifth Assessment Report published in 2014 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 impact on the crops, soils, livestock and pests. The present report discusses the impact of climate change on Indian agriculture and the technologies that may be needed for climate resilient agriculture.

Climate change prediction points a warmer world within the next 50 years, a trend that is increasingly being supported by 'ground-truth'. Climate change threatens to increase the crop losses, increase in the number of people facing malnutrition, and changing the development pattern of plant diseases and insect-pests. Agriculture production of rainfed regions, which constitute about 68% of the area under cultivation and account for about 40-45% of the total production in India, varies from year to year. Hence, in order to sustain and enhance the production of the rainfed crops of semi-arid tropics, it is necessary to use the knowledge of climate variability to tailor the practical innovative cropping pattern and insect-pest and disease management for location specific agro-climatic zone.

Current estimates of change in climate indicate an increase in global mean annual temperatures of 1ºC by 2025 and 3ºC by the 2100. Variability in rainfall pattern and intensity of rain are expected to increase. Increasing concentration of greenhouse gases (CO_2 and O_3) would result in increase in global precipitation of 2 ± 0.5ºC per 1ºC warming. Overall, changes in these elements will result in i) warmer and more frequent hot days and nights ii) erratic rainfall distribution pattern leading to drought or high precipitation and iii) drying of rainfed semi-arid tropics (SAT) in Asia and Africa.

2. Climate Change in Global and Indian Context

The evidence of changing climate from observations has grown significantly during recent years. At the same time improved ways of characterizing and quantifying uncertainty have highlighted the challenges that remain silent for developing long-term global and regional climate quality data records. The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880–2012, when multiple independently produced datasets exist and about 0.72°C [0.49°C to 0.89°C] over the period 1951–2012. The total increase between the average of the 1850–1900 period and the 2003– 2012 period is 0.78 [0.72 to 0.85] °C and the total increase between the average of the 1850–1900 period and the reference period for projection 1986”2005 is 0.61 [0.55 to 0.67] °C. This is based on the single longest dataset available. Averaged over the mid-latitude land areas of the Northern hemisphere, precipitation has likely to be increased since 1901 (medium confidence before and high confidence after 1951). For other latitudinal zones area-averaged long-term positive or negative trends have low confidence due to data quality, data completeness or disagreement amongst available estimates. It is very likely that the numbers of cold days and nights have decreased and the numbers of warm days and nights have increased globally since about 1950. However, it is likely that heat wave frequency has increased during this period in large parts of Europe, Asia and Australia. It is likely that since about 1950, the number of heavy precipitation events over land has increased in more regions than it has decreased.

The projected change in global mean surface air temperature is likely be in the range from 0.3 to 0.7°C (medium confidence). It is more likely that the global mean surface air temperature for the period 2016–2035 will be around 1°C above the mean temperature of 1850–1900. Zonal mean precipitation is likely to increase in high and some of the mid latitudes, and is more likely than not decrease in the subtropics. At more regional scales precipitation changes may be influenced by anthropogenic aerosol emissions and will be strongly influenced by natural internal variability. Models project near-term increases in the duration, intensity and spatial extent of heat waves and warm spells. These changes may proceed at a different rate than the mean warming. The frequency and intensity of heavy precipitation events over land are likely to increase on average in the near term. However, this trend will not be apparent in all the regions because of natural vari-ability and possible influences of anthropogenic aerosols.

In the last 100 years the mean annual surface air temperature of India has increased by 0.4-0.6°C (Rupakumar 2002). Annamalai *et al.* (2010) reported decreasing rainfall tendency in both southwest and northeast monsoon seasons in most parts of central and northern India. In contrast, peninsular parts of India particularly over the region from 9-16°N encompassing the rice growing areas showed an increasing rainfall tendency. This increase was particularly strong during the northeast monsoon season.

Lal *et al.* (1995) projected the climate change scenario for Indian subcontinent and the results indicated an increase in annual mean maximum and minimum surface air temperatures by 0.7°C and 1.0°C respectively over land in the 2040s as compared to the 1980s level. Shakeel *et al*. (2009) have reported a projected increase in temperature by 0.4 - 2.0°C in *Kharif* and 1.1 - 4.5°C during *Rabi* by 2070 over Indian region. The IPCC in its fourth assessment report has predicted 2.7- 4.3°C temperature rise over India by 2080s (IPCC, 2007). Rupakumar *et al.* (2006) projected a temperature rise of 2.9°C and 4.1°C for India under B2 and A2 scenarios of SRES respectively, in 2080s relative to 1970s. The CMIP3-based model ensemble mean projects a warming of 3.19°C under the A_1B scenario for 2080s compared to the 1970s baseline. Krishankumar *et al.* (2010) projected a warming of 3.5°–4.3°C over the same period for the A_1B scenario. The CMIP3-based model ensemble mean projects a warming of 3.19°C under the A_1B scenario for 2080s compared to the 1970s baseline (Rajiv Kumar Chaturvedi *et al.*, 2012). All India annual mean temperature increases by 1.7°C–2.02°C by 2030s under different RCP scenarios and by about 2°C–4.8°C by 2080s, relative to the pre-industrial base (1880s). The CMIP5-based model ensemble projects a warming of 2.8°C and 4.3°C under the RCP6.0 and RCP8.5 scenarios respectively, for 2080s compared to the 1970s baseline (Rajiv Kumar Chaturvedi *et al.* 2012). According to Khan *et al.* (2009), the mean rainfall of India for the SRES is projected to increase by 10% during *Kharif* and *Rabi* seasons during 2070 from the reference year 2010. The study conducted by Rupakumar *et al.* (2003) revealed that marked increase in rainfall in the 21st century is likely to be evident after 2040s in India. They have also inferred that the number of rainy days is likely to increase by 5-10 days in the foot hills of Himalaya and Northeast India. All-India annual precipitation increases by 1.2–2.4% by 2030s under different RCP scenarios and by 3.5–11.3% by 2080s, relative to the pre-industrial base. Precipitation is projected to increase almost all over India except for a few regions in short-term projections (2030s). The RCP2.6 experiences the least increase in precipitation with the projected precipitation change varying from 0 to 15%, while and RCP8.5 is associated with the largest changes in precipitation, with the projected precipitation changes varying from 5 to 45% (Chaturvedi *et al.* 2012).

3. 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 rain. 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 their 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 fertilizer use efficiencies, and increase in evapo-transpiration. Climate change also have considerable indirect effect 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 land, and availability of energy.

Critical challenges that agriculture sector would face in the event of climate change are (i) water availability as result of changing rainfall patterns, alteration in stream flow and increase in crop water demand (ii) deterioration of water quality due to sea water intrusion, transport of salts from the deeper soil layers as a result of over exploitation of aquifers and faulty irrigation practices (iii) Increased frequency and intensity of extreme weather events such as droughts, floods and cyclones and these would affect the production levels more than the impact of mean changes in the climate (iv) heat stress due to higher temperature at critical stage of the crop growth (v) unpredictable change in pest and disease load. There is also possibility of minor pest becoming major pest with changing climatic condition.

The classified impacts on crops, water, livestock, fisheries and pest and diseases are presented below (Aggarwal et al. 2009):

Crops

- Increase in ambient CO_2 is beneficial since this leads to increased photosynthesis in several crops, especially crops with C3 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 season.
- 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, Bhramaputra 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 water.

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 impact on vector-borne diseases of livestock by the expansion of vector population. 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 demand.
- 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 harvest.
- Impact 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.

Insects and diseases

- Extension of geographical range of insect-pests and pathogens
- Changes in population growth rates of pathogens and insect-pests
- Changes in relative abundance and effectiveness of biocontrol agents
- Changes in pathogen/insect-pest × host × environment interactions, and loss of resistance in cultivars containing temperature-sensitive genes
- Emergence of new diseases/pest problems and increased risk of invasion by migrant diseases and pests
- Reduced efficacy of different components of disease and insect-pest management.

4. State of the Art of Research on Climate Change and Agriculture

The climate change would have major implications on food and nutritional security, particularly in developing countries of the semi-arid tropics, where the need to increase and sustain food production is most urgent. Chickpea and pigeon pea are grown in different cropping systems by resource poor farmers in harsh, climatically and economically volatile environments. Research on the effect of climate variables on host-pathogen/pest interactions is critical to develop durable resistances. Epidemiological knowledge combined with biophysical and socio-economical understanding is required to achieve sustainable management.

The Inter-governmental Panel on Climate Change (IPCC), in its 5th Assessment Report warned for dire consequences of climate change on human health, settlements and natural resources, if no measure is taken to curb the ill-effects of global warming. The region-wise findings of the report have some key messages for agriculture and food security for India. It observes that, the coming years will see more extreme weather events (floods, cyclones, cloud bursts, unseasonal excessive rains and drought, etc.) in most parts of the globe and India will be among the most affected countries. It goes on to suggest that severe stress on fresh water resources in South Asia and China (Himalayan river basins) may become a reason for armed conflict in the region by middle of the 21st century.

According to IPCC report, India will experience decrease in seasonal mean rainfall and an increase in extreme precipitation during monsoon. This will increase both floods and drought. Freshwater resources will be affected due to combination of climate change and unsustainable practices. It is projected that there will be reduction in wheat yield in the Indo-Gangetic plains; and substantial increase in heat stress for rice, affecting its yield. Coastal flooding will affect people and agriculture and also affect tourism in India. Some fish and other marine animals will face extinction by 2050, affecting fishing community. Glaciers in Himalaya continue to shrink affecting run-off and water resources downstream. Other that agriculture, temperature variations will lead to outbreak of diseases as well and disturb the already poor health indicators of the country.

The report suggested that severe impact of climate change can be avoided or minimized provided countries act collectively and quickly. To deal with these consequences and ensure food security and livelihoods, adaptation to climate change is essential. Adopting carefully chosen adaptation and resilience measures could improve crop yields as much as 15-20%. The IPCC recommendations include altering planting dates to match the shifting growing seasons, using crop varieties that might be more tolerant to changing climatic patterns and better management of agri-inputs particularly water and fertilizer. Efforts to reduce carbon emissions would have minimal impact on growth, about 0.06% of GDP. It recognizes that sustainable development and equity have to be the basis for climate policy, which should intersect with other goals related to health, food security, poverty eradication, environmental quality and energy access. India is arguing for this view for a long period of time.

In India, it has been projected that under the scenario of a 2.5°C to 4.9 °C temperature rise, rice yields will drop by 32-40% and wheat yields by 41-52%. *Kharif* rainfall is going to increase due to climate change and this might be positive for *kharif* crops. Further, for *kharif* crops, a one-degree rise in temperature may not have big implication on productivity. However, temperature rise in *rabi* season will impact production of wheat, a critical food-grain crop. Study conducted by Indian Agricultural Research Institute (IARI) showed that *rabi* crop will be affected seriously and every 1°C increase in temperature reduces wheat production by 4-5 million tons. Productivity of most cereals would decrease due to increase in temperature and decrease in water availability, especially in Indo-Gangetic plains. The loss in crop production is projected at 10-40% by 2100, depending upon the modelling technique.

Recent surveys conducted and reports from Semi Arid Tropics (SAT) regions indicated that dry root rot (*Rhizoctonia bataticola*) in chickpea and charcoal rot (*Macrophomina phaseolina*) in sorghum had increased many folds in last 2-3 years due to rise in temperature and prolonged moisture stress (Sharma and Pande, 2013). Similarly high intermittent rains resulted in outbreak of phytophthorablight in pigeonpea (*Phythophthora drechsleri*f. sp.*cajani*) in SAT regions in the last 5 years (Pande and Sharma 2009; Pande *et al.,* 2011). Increased severity of alternaria blight in pigeonpea (Sharma *et al.,* 2013), foliar blast (*Pyricularia grisea*) in pearl millet during the past few years could be also attributed to changes in rainfall pattern during the rainy season. *Helicoverpa armigera* (Sharma, 2005), the most devastating crop pest will become more abundant as a result of rapid generation turnover, lesser activity of natural enemies, and lower efficacy of control measures. Its northern limits will extend to the temperate zone as a result of global warming. *Maruca vitrata*, the legume pod borer, will become more serious with increase in precipitation and un-seasonal rains. Incidence of shoot fly and stem borers will increase in areas subjected to prolonged drought; while the severity of gall midge and leaf hoppers might decline under drought stress. Drought stressed crops will suffer greater damage because of greater vulnerability of stressed plants to insect damage. Increased CO_2 levels will result in decreased production of secondary metabolites, and thus reduce the plants own defenses against insect attack.

Relationships between pests and their natural enemies will change as a result of global warming, resulting in both increases and decreases in the status of individual pest species. Quantifying the effect of climate change on the activity and effectiveness of natural enemies will be a major concern in future pest management programs. The majority of insects are benign to agro-ecosystems, and there is much evidence to suggest that this is due to population control through inter-specific interactions among pests and their natural enemies – pathogens, parasites and predators. Oriental armyworm (*Mythimna separata*) populations get increased when extended period of drought (which is detrimental to the natural enemies) is followed by heavy rainfall (Sharma *et al*. 2001).

With the current trends in global warming and climate change, it is likely that most pests will have a cosmopolitan range wherever the climate is favorable and the hosts are available. Prediction of such changes, and range and diversity in pests niches should help develop better control measures, as well as adapt IPM strategies to minimize pest incidence (Sharma, 2010). There is a need for a greater understanding of the effect of climate change on the efficacy of synthetic insecticides, their persistence in the environment, and development of resistance in pest populations to the pesticides.

4.1. Adaptation of Indian Agriculture to Climate Change

Potential adaptation strategies to deal with the impact of climate change are developing cultivars tolerant to heat and salinity stresses 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 below.

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. 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.

Efficient use of natural resources such as water is highly critical for adaptation to climate change. With hotter temperature and changing precipitation pattern, 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 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. 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 fertilizer which helps good plant stand, enhanced nutrient use efficiency and increased yield (Pathak *et al.*, 2012). 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 structure.

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 effect 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, oil seed-wheat and direct-seeded rice-wheat. The latter system 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.

Changes in temperature and variability in rainfall would affect pests incidence and their virulence on 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, speed 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 (Fedoroff *et al.,* 2010). 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 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 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.

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 modeling 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 the researchers and administrators develop contingency plans.

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 vulnerabilities. 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 charged 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.

5. Initiatives of Govt. of India for Climate Change Adaptation in 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. These efforts have provided valuable inputs in terms of the regional and national level impact of climate variability and climate change on major food crops, horticulture and livestock productions. It has launched the National Mission for Sustainable Agriculture (NMSA) which 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. These include improved crop seeds, livestock and fish culture; water use efficiency; pest management; improved farm 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 greenhouse 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 X 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 impact and adaptation of Indian agriculture to climate change covering not only grain crops but also horticulture, natural resource, livestock and fisheries. The program covering 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 68% 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 over nearly 160 districts in the XII 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 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 fertilizer 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 Plan 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 to the components for women farmers.

Adaptation 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 is a multi-institutional programme, which integrates the activity from many organizations 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 Fertilizers and Dept. of Economic Affairs to monitor various parameters i.e., rainfall, water storage, sowing status, fertilizers, pest & diseases, prices and availability of seeds.

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. Recently, the Govt. has launched the Pradhan Mantri Fasal Bima Yojana (Prime Minister Crop Insurance Scheme) to enable farmers avail insurance cover against crop loss on account of natural calamities.

6. Research Undertaken Under National Mission on Strategic Knowledge for Climate Change (NMSKCC) as Part of Climate Change Programme of DST

6.1. Project at Tamil Nadu Agricultural University

Assessing impacts and developing adaptation strategies for agriculture in Tamil Nadu

6.1.1. Objectives

i. Examining the influence of the global climate drivers (ENSO/IOD) on climate of Tamil Nadu at river basin scale.

ii. Investigating the impact of the climate change on major agricultural crops in five major river basins of Tamil Nadu (Cauvery, Thamirabarani, Vaigai, Parambikulam-Aliyar and Palar) through integrated modeling approach (climate, hydrological and crop weather models)

iii. Designing innovative adaptation technologies (including microbial inoculants, nanoinputs to enhance water and nutrient use efficiencies) and assessing its feasibility and economic viability to combat climate change impacts.

iv. To ensure dissemination of climate change driven technologies among farming communities through the existing AAS network and assist in developing State action plan on climate change related to agriculture sector

6.1.2. Methodology

The agriculture in India is greatly influenced by climate change and extreme weather events. The project will develop baseline data pertaining to water, nutrient and productivity of various crops in major river basins of Tamil Nadu State. Influence of the global climate drivers (ENSO / IOD) on climate of Tamil Nadu at river basin scale will be analysed. The various climate change scenarios perceived by the IPCC will be modelled to study the impact on the hydrology and water availability using hydrological models. For getting future climate data at closure grid size (25 x 25 km), GCMs will be used. Soil and Water Assessment Tool (SWAT) will be employed to map the hydrology of the study area for baseline and future scenarios. The outcome of the climate and SWAT models will be coupled with crop weather model (DSSAT) to study the impact of water availability and changing climate on crop productivity. Based on the model outputs, various adaptation technologies will be designed to improve the water and nutrient use efficiencies.

6.1.3. Results

i. Situation analysis

Situation analysis report has given a clear picture on the current status of the river basin in terms of climate, major soil types, land use pattern, major crops grown, institutions in the basin and role of private sectors which formed the basis for structuring of the researchable issues. Current knowledge of the farmers had been documented. Climate related risks in the river basins were ranked based on the likelihood probability of occurrence and their consequence on crops and livelihoods. Also documented non-climatic stress and sensitivities that aggravate the climate change issues. Existing local adaptive capacities of the farmers were also documented.

Focus Group Discussion made with the farmers of Cauvery basin and PAP Basin

ii. **Influence of the global climate drivers (ENSO/IOD) on climate of Tamil Nadu at river basin scale and its influence on hydrology and rice productivity**

Simultaneous correlation and lag correlation were performed between SOI / IOD and rainfall using the gridded daily rainfall data at 0.5 x 0.5 degree resolution accumulated for Southwest and Northeast monsoon seasons over different river basins of Tamil Nadu. Historical SOI values were segregated into Neutral (-5.5>SOI <+ 5.5), El-Nino (SOI≤-5.5), La Nina (SOI≥+5.5) to correlate with rainfall. Major findings are given below:

a) Results of the correlation study indicated that there was no significant correlation existed between El-Nino and SWM rainfall at river basin scale. If the El-Nino events are segregated into weak and strong phases, then the strength of correlation is improved. Weak El-Nino years (SOI between -5.5 and -10) had positive correlation with SWM rainfall of southern, central and northwestern parts of Tamil Nadu. In strong El-Nino years (SOI between -10 and -35), a positive correlation was observed in the eastern and northeastern parts of Tamil Nadu as well as in most parts of the eastern coast.

b) All La-Nina years had positive correlation with SWM rainfall over most parts of Western Ghats and northern coastal area. Weak El-Nino years had positive correlation with SWM rainfall over southern parts of Western Ghats and central Tamil Nadu. Strong El-Nino years had the positive relationship with rainfall covering the whole of Western Ghats and eastern coast.

c) As far as NEM is concerned, only southern Tamil Nadu showed correlation upto 0.4 with El-Nino condition, while all other parts had weak correlation. Weak El-Nino years had good negative relationship with NEM rainfall over entire Western Ghats, east coast and northern pockets of Tamil Nadu. In contrast, strong El-Nino years exhibited positive correlation with northern and central Tamil Nadu including eastern coast for NEM rainfall.

d) In all La-Nina years, northern and central Tamil Nadu showed negative relationship while in weak La-Nina years, the negative relationship with NEM rainfall extended to total Tamil Nadu except few parts of western and northern regions of Tamil Nadu. In strong la-Nina years, except Cauvery basin all other parts showed positive relationship with NEM rainfall.

e) Analysis on Cauvery basin using SWAT model indicated that the El Niño episode had a good linkage with rainfall, hydrology and rice productivity in the Cauvery river basin, India. Major share of rainfall is received during northeast monsoon (44.44%) followed by southwest Monsoon seasons (36.18%) and the total flow gradually increased from March to September. Soil water recharge increased from April and attained its maximum during September through December. ET is met in most of the months except during summer (March – May). El Niño years received more rainfall (with high inter annual rainfall variability of 809.3 mm to 2366 mm), which resulted in high soil water recharge including percolation and soil water availability in the surface layers.

f) The mean rice productivity was shifted to up in El Niño and normal years indicating the possibility of getting more rice yields with less crop production risk compared to La Niña years. This behaviour could be well utilized for forecasting the rice crop productivity under different ENSO conditions and can help the policy makers to decide on the water allocation as well as to design import/ export policies.

iii. Expected change in climate over Cauvery basin

Future climate predictions derived from the ensemble of 16 GCMs for Cauvery basin indicated the increase in rainfall between 7 and 21% towards mid-century (2040 -2069) while this increase is

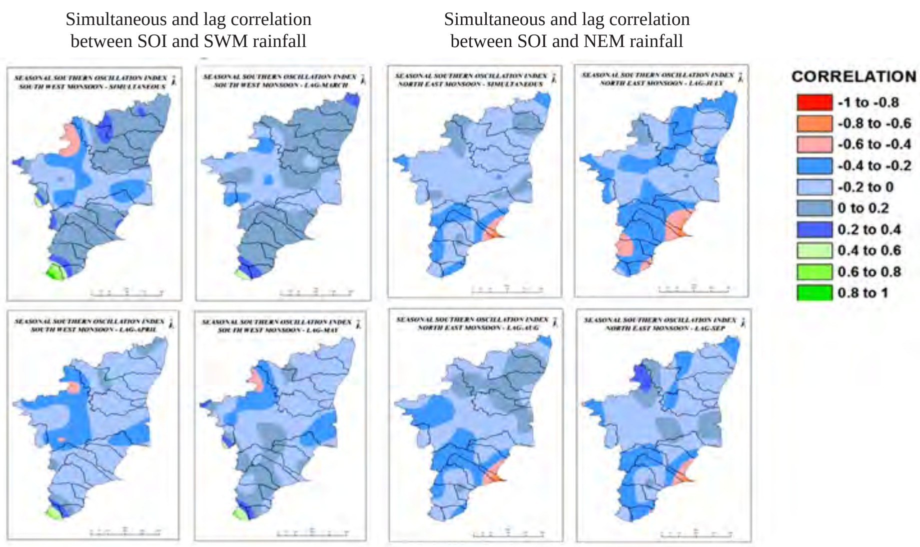


Fig.1. SOI simultaneous and Lag correlation with SWM and NEM rainfall

projected to be between 10 and 33% in end century (2070-2099) compared to baseline (1971-2005). Temperature is expected to increase by 1.5 to 2 ^{0}C and 3 to 4.5 ^{0}C in the mid and end century time scale.

iv. Calibration and validation of impact models

Impact models such as Soil and Water Assessment Tool (SWAT), DSSAT were calibrated and validated for the study region to assess the impact pf climate change on hydrology and crops productivity. These models were also used for developing adaptation strategies.

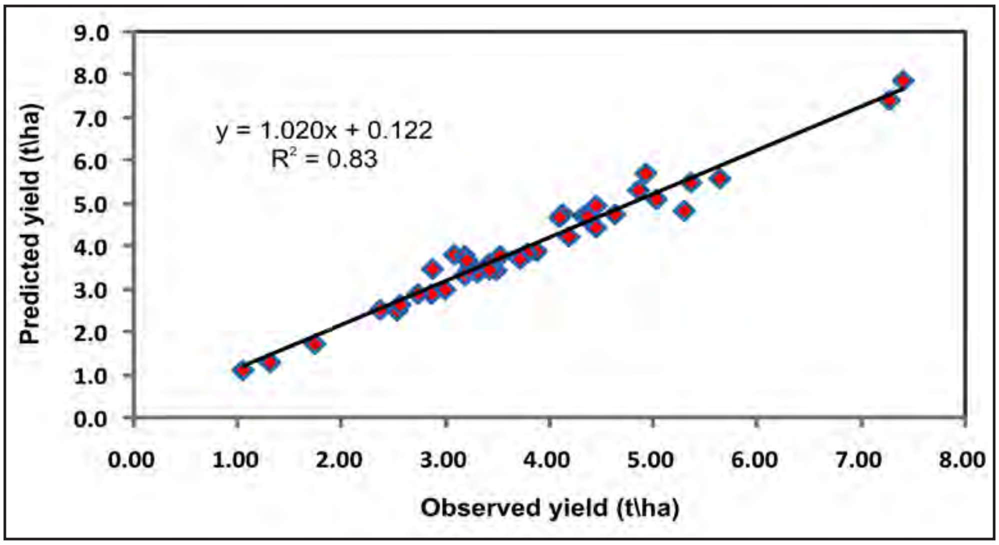
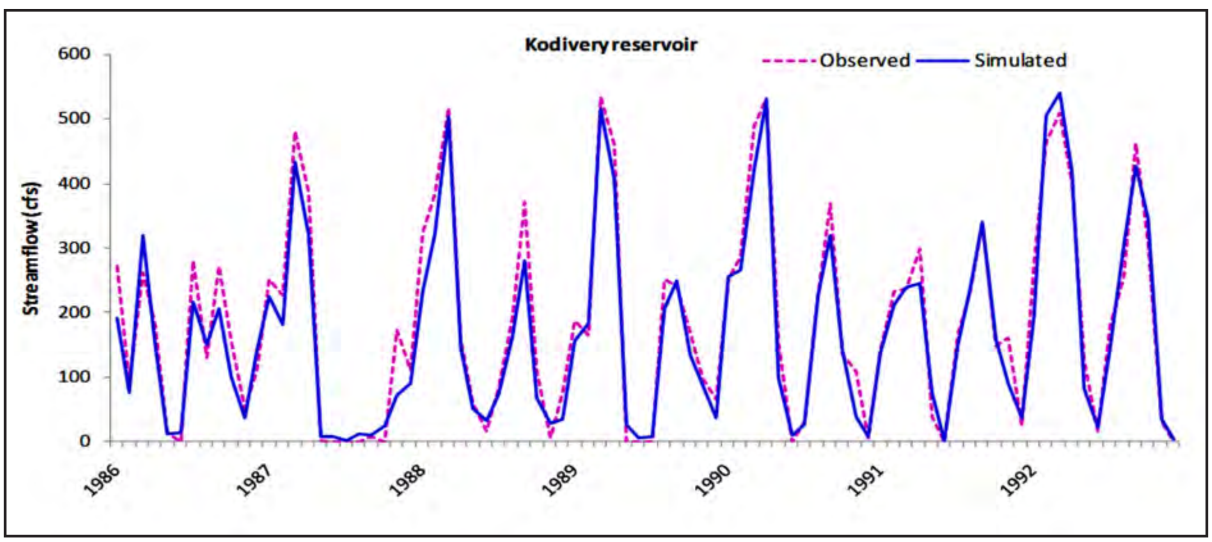


Fig. 2. Comparison of observed and SWAT simulated crop yield over Cauvery basin

v. Impact of climate change on the hydrology of Cauvery basin

The SWAT model results showed that in the mid century, the predicted increase in annual Potential Evapotranspiration (PET) for Cauvery basin would vary from 3 to 4.5% and 8.4 to 9.3% for the mid



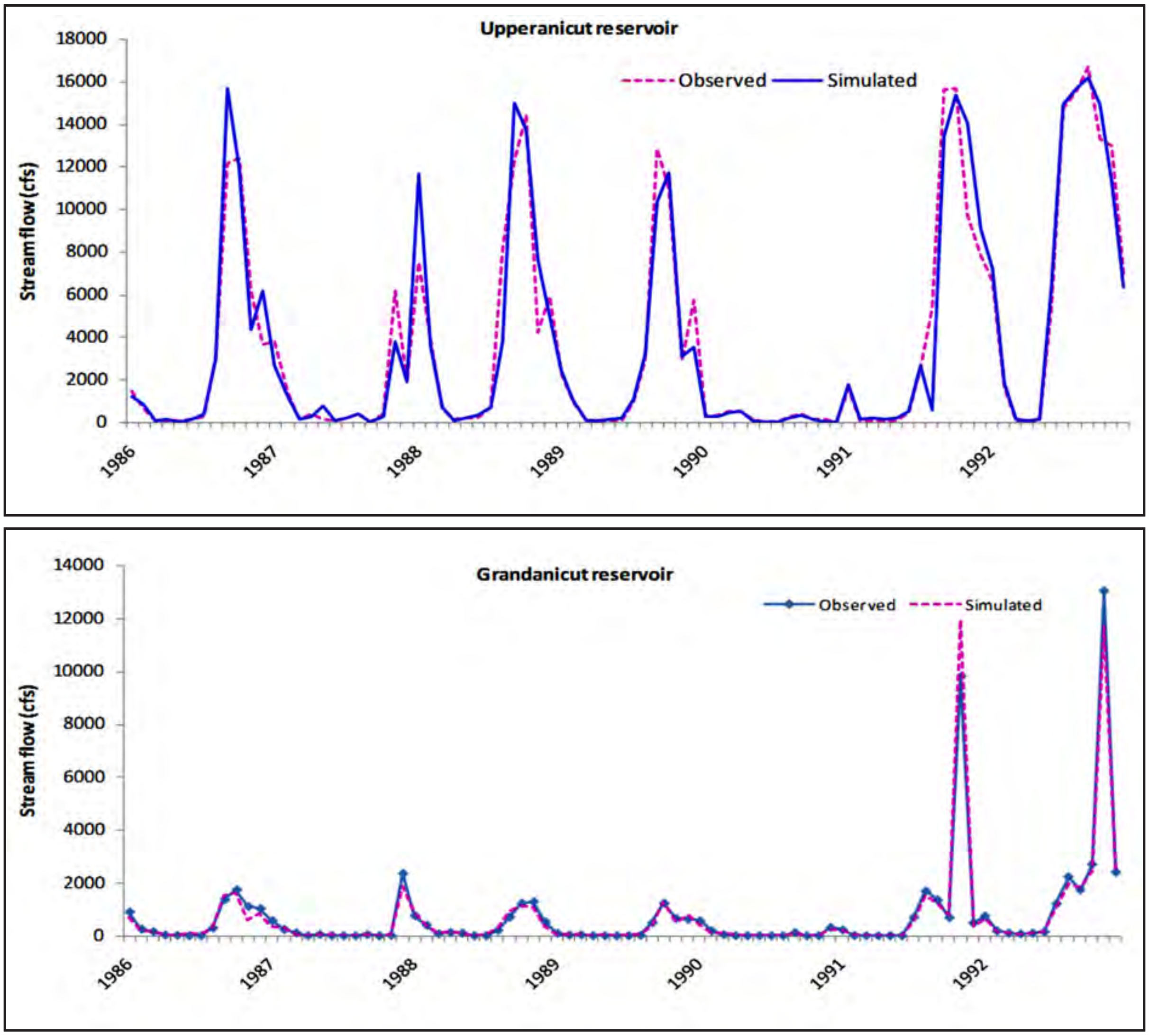


Fig. 3. Observed and simulated monthly stream flow (cfs) for the Cauvery basin over the calibration (1986–1989) and validation (1990–1992) time periods.

and end century scenario respectively over the present level. Annual water yield is expected to increase by 14 to 21% during mid-century and is projected to increase further by 20 to 27% towards end century. The annual soil water storage is also predicted to increase by 5 to 14 % and 7 to 18% in the mid and end century respectively.

vi. Climate change impacts on irrigation water requirement for paddy in Cauvery delta region of Tamil Nadu

Results of SWAT model indicated that climate change impacted the atmospheric water demand and irrigation water requirement of paddy in the delta portion of Cauvery basin in Tamil Nadu. The PET is expected to increase in the mid and end century. As a result of this water requirement of rice crop is also expected to increase in future.

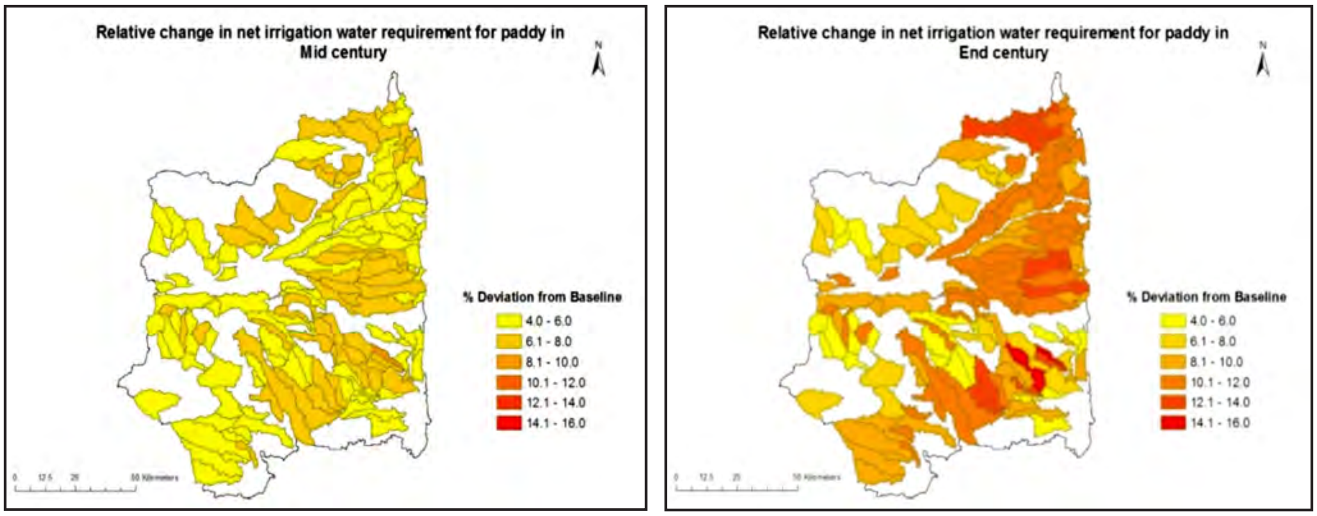


Fig. 4. Changes (%) in irrigation water requirement for paddy during mid and end century compared to the baseline

vii. Sensitivity analysis for change in temperature, rainfall and CO_2 on maize

Different combinations of change in temperature, rainfall and CO2 concentration were simulated using Ceres–Rice model embedded in DSSAT model.

Table 1. Sensitivity combinations and their yield for temperature change.

Change in Temp(˚C)	Rainfall change (%)		CO_2 Concentration (ppm)		Yield		Deviation from control (%)	
	Avg	Range	Avg	Range	Avg	Range	Avg	Range
-1.0 to 0.0	10.5	-43 to 40	536	355 - 744	6542	6062-7143	12	4 to 23
0.1 to 2.0	7.2	-44 to 49	612	340 - 887	5845	4987-6583	0.4	-14 to 13
2.1 to 4.0	5.4	-48 to 48	638	366 - 875	5225	4675-5553	-10	-5 to -20
4.1 to 6.0	-8.4	-50 to 45	600	333 - 898	4821	3867-5605	-17	-4 to -34
6.1 to 7.9	-2.2	-37 to 44	656	380 - 883	4179	2700 - 5637	-28	-3 to -54

Yield of Control Treatment: 5821 kg ha^{-1}

Sensitivity analysis gave a clear indication on the impact of combination of effect of change in temperature and precipitation on crops with and without CO_2 fertilization. This would help in designing appropriate adaptation strategies.

Table 2. Sensitivity combinations and their yield for change in rainfall.

Rainfall change (%)		Change in Temperature (˚C)		CO_2 Concentration (ppm)		Yield		Deviation from control (%)	
Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range
-44	-50 to -40	3.2	-0.1 to 5.4	642	346 - 847	5445	4340 - 6721	-6.5	-25.4 to 15.5
-35	-38 to -32	5.9	3.9 to 7.6	649	333 - 883	4601	2700 - 5637	-21.0	-53.6 to -3.2
-25	-29 to -21	4.1	-0.3 to 7.3	619	340 - 871	4960	3446 - 6741	-14.8	-40.8 to 15.8
-15	-20 to -11	4.0	0.7 to 6.7	570	418 - 898	4859	3363 - 5537	-16.5	-42.2 to -4.9
-4	-9 to 0	4.7	0.5 to 7.9	618	399 - 836	4753	3163 - 5986	-18.4	-45.7 to 2.8
6	1 to 10	2.5	-0.5 to 7.5	682	563 - 815	5623	4128 - 6792	-3.4	-29.1 to 16.7
15	11 to 20	3.8	-0.8 to 7.2	565	355 - 852	5266	3873 - 6347	-9.5	-33.5 to 9
25	21 - 30	3.3	-1.0 to 7.8	679	440 - 887	5440	3317 - 7143	-6.5	-43 to 22.7
35	31 to 40	2.5	-0.9 to 6.9	529	366 - 866	5269	4009 - 6572	-9.5	-31.1 to 12.9
45	41 to 49	2.8	0.6 to 7.2	615	412 - 861	5165	3102 - 6476	-11.3	-46.7 to 11.3

Table 3. Sensitivity combinations and their yield for change in CO_2concentration.

CO_2 Concentration (ppm)		Change in Temperature (˚C)		Rainfall change (%)		Yield		Deviation from control (%)	
Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range
367	333-399	2.9	-0.8 to 7.6	-8.2	-46 to 39	4691	2700 - 6313	-19.4	-53.6 to 8.5
449	403-500	3.8	-0.9 to 7.2	8.8	-35 to 45	4735	3102-6572	-18.6	-46.7 to 12.9
552	504-599	3.4	-0.4 to 7.9	0.3	-50 to 43	5056	3163 - 6468	-13.1	-45.7 to 11.1
651	604-691	2.9	-1.0 to 7.8	16.9	-35 to 49	5473	3317-7143	-6.0	-43 to 22.7
746	700-798	3.8	-0.1 to 7.5	-11.3	-47 to 35	5472	4128-6721	-6.0	-29.1 to 15.5
850	802-898	4.4	0.6 to 7.3	-2.3	-45 to 47	5469	4428-6476	-6.0	-23.9 to 11.3

Yield of Control Treatment: 5821 kg ha^{-1}

viii. Study on the response of C_3 (Rice) and C_4 (Maize) plants to elevated temperature and CO_2

Impact on C_3 (rice) and C_4 (maize) plants to elevated temperature and CO_2 were studied under ambient as well as controlled condition using Temperature Control Chamber (TCC: ambient temperature + 4°C) and Soil Plant Atmosphere Research (SPAR: ambient temperature + 4°C and 550 ppm CO_2) during *rabi* (September-January), 2013-14 at the Agro-Climate Research Centre (ACRC) of Tamil Nadu Agricultural University (TNAU), Coimbatore. Results clearly indicated that increase in temperature with or without CO_2 enrichment affected the phenology and productivity of C_3 and C_4 plants with different magnitude. Temperature increase alone had negatively affected the C_3 crop (rice) more compared to C_4 crop (maize). However, CO_2 enrichment had compensated the negative impact of elevated temperature to certain extent. Rice had responded more positively to CO_2 enrichment compared to maize under elevated temperature.

Table 4. Effect of ambient and controlled conditions on yield of rice and maize crop.

Treat ments	RICE (C_3)				MAIZE(C_4)			
	Grain yield (g per plant)	Straw yield (g per plant)	DMP (g per plant)	Grain conversion percentage	Grain yield (g per plant)	Straw yield (g per plant)	DMP (g per plant)	Grain conversion percentage
T_1	38.15	51.12	93.00	41.02	107.25	152.34	270.59	39.64
T_2	21.00 (-45%)	39.06 (-23%)	65.13 (-30.3%)	32.31 (-21.0%)	80.88 (-24%)	133.66 (-12%)	223.55 (-17.4%)	36.18 (-21.0%)
T_3	24.68 (-35%)	47.63 (-15%)	71.06 (-23.7%)	33.78 (-15.3%)	84.59 (-21%)	138.31 (-9.2%)	232.14 (-14.2%)	36.54 (-15.3%)
SEd	0.1713	0.284	0.4643		0.5507	0.8609	1.47	
CD (P=0.01)	0.4931	0.818	1.3363		1.5855	2.4785	4.2319	

ix. Designing innovative adaptation technologies - Screening crop cultivars for elevated temperature

Experiment was carried out at Agro Climate Research Centre (ACRC) of Tamil Nadu Agricultural University (TNAU), Coimbatore under 5 ^{0}C elevated temperature. Varieties of different duration were taken and staggered planting was done to coincide the flowering period of all the varieties under the study to understand the influence of the elevated temperature. Same varieties were also grown under ambient condition to compare the effect.

In rice crop, ADT 40, Vellai samba and karthigai samba cultivars recorded highest spikelet fertility in control chamber (with 5^{0}C elevated temperature) compared to open condition. Among the 18 long duration rice cultivars, vellai samba and karthigai samba exhibited higher tolerance to elevated temperature (upto 43 ^{0}C) and these varieties could be used in the breeding programmes for developing heat tolerant cultivars.

x. SRI as an adaptation technology to changing climate in rice

Simulation of well calibrated and validated DSSAT- CERES- Rice model indicated that the rice crop would be greatly affected due to changing climate and the yield is expected to go down under future warmer climatic condition. Some of the adaptation technologies like timely planting and practicing system of rice intensification (SRI) would help in sustaining the rice yields under changing climatic condition. During *Kharif* season, SRI produced higher yield by 33.1% (25.1 %) with water saving of 16% (7.8 %) over traditional flooded rice cultivation.

xi. Identification of best planting window for rice in the context of future climate change: A controlled condition experiment

Rice crop grown under climate control chamber with elevated temperature (ambient +4°C) and CO_2 enrichment (650 ppm) recorded reduced growth characters such as number of tillers, leaf area index and dry matter production. It has also recorded lower grain and straw yields due to lesser number of productive tillers and lesser number of filled grains. Crop planted on 1st June registered higher growth characters like stem height, number of tillers, leaf area index and dry matter production than other dates of sowing. Among the different sowing windows tested to manage climate change, 1st June sowing yielded more than advanced or delayed planting under both ambient as well as under modified climatic conditions.

xii. Effect of nano fertilizers on the productivity and green house gas fluxes in rice cultivation

Impact study of NH_4^+–N loaded nano-zeolite on the growth and green house gas fluxes in rice cultivation under different moisture regimes clearly indicated enhanced nitrogen availability, crop growth in addition to minimizing the emission of methane from rice soils. Due to the combined effect of growth enhancement and lesser methane flux, nitrogen loaded nano zeolite might be a potential and eco-friendly source of N for rice cultivation.

6.1.4. Summary of Results

- Analysis of relationship between El-nino and rainfall indicated that, in strong El-Nino years (SOI between -10 and -35), a positive correlation was observed in the eastern and northeastern parts of Tamil Nadu as well as in most parts of the eastern coast. As far as NEM is concerned, only southern Tamil Nadu showed correlation upto 0.4 with El-Nino condition, while all other parts had weak correlation.
- The mean rice productivity was shifted to up in El Niño and normal years indicating the possibility of getting more rice yields with less crop production risk compared to La Niña years.
- Future climate predictions derived from the ensemble of 16 GCMs for Cauvery basin indicated the increase in rainfall ranges between 7 and 21% towards mid-century (2040 -2069) while this increase is projected to be between 10 and 33% in end century (2070-2099) compared to baseline (1971-2005). Temperature is expected to increase by 1.5 to 2 ^{0}C and 3 to 4.5 ^{0}C) in the mid and end century time scale.
- Annual Potential Evapotranspiration (PET) for Cauvery basin would vary from 3 to 4.5% and 8.4 to 9.3% for the mid and end century scenario respectively. Annual water yield is expected to increase by 14 to 21% during mid-century and is projected to increase further by 20 to 27% towards end century. The annual soil water storage is also predicted to increase by 5 to 14% and 7 to 18% in the mid and end century respectively.
- Increase in temperature with or without CO_2 enrichment affected the phenology and productivity of C_3 and C_4 plants with different magnitude. Temperature increase alone has negatively affected the C_3 crop (rice) more compared to C_4 crop (maize). However, CO_2 enrichment had compensated the negative impact of elevated temperature to certain extent.

- Adaptation technologies identified for changing climate are: Cultivation of rice crop in SRI method, planting the crop in best planting window, growing heat and drought tolerant cultivars and application of NH_4^+–N loaded nano-zeolite.
- NH_4^+–N loaded nano-zeolite application enhanced nitrogen availability, crop growth in addition to minimizing the emission of methane from rice soils.

6.1.5. Strategic Knowledge generated

- Current climate assessment and climate risk ranking in Tamil Nadu indicated that the **drought during crop growing season is the most limiting factor** for crop production.
- Global climate drivers such as **ENSO and IOD influence rainfall at regional scale**. Weak El-Nino years (SOI between -5.5 and -10) had positive correlation with SWM rainfall while, it had negative relationship with NEM rainfall over most part of Tamil Nadu. All La-Nina years had positive correlation with SWM rainfall of Tamil Nadu. Hence, ENSO forecast could be utilized for strategic farm management planning such as choice of crop, land allocation, etc., to capture the benefit of expected situation.
- **EN-Nino/Southern Osciallation (ENSO) impacts hydrology and rice productivity at river basin scale.** The mean rice productivity was shifted up in El Niño indicating the possibility of getting more rice yields with less crop production risk as a result of higher water availability. This behaviour could be well utilized for forecasting the rice crop productivity under different ENSO conditions and can help the policy makers to decide on the water allocation as well as import/export policies.
- **Climate change would increase the irrigation water requirement for paddy in Cauvery delta region of Tamil Nadu** by 8 and 14 % during mid and end century respectively compared to current water requirement as a result of increase in PET.
- **Increase in temperature negatively impacted C_3 (Rice) plants more compared to C_4 (Maize) plants.** However, CO_2 enrichment has compensated the negative impact of elevated temperature to certain extent. Rice has responded more positively to CO_2 enrichment compared to maize under elevated temperature.
- **Screening rice cultivars for elevated temperature** proved the potentiality of cultivars such **asvellai samba and karthigai samba to withstand** upto 43 ^{0}C without productivity loss. Hence, these varieties could be used in the breeding programmes for developing heat tolerant cultivars.
- **System of Rice Intensification** (SRI) would help in sustaining the rice yields under changing climatic conditions. There is water saving of around 20% with yield enhancement upto 22% with SRI method of rice cultivation.
- Even under changing climatic conditions in the future time scale, **June 1st planting would be the best time for rice crop in Tamil nadu.**
- Application of **NH_4^+–N loaded nano-zeolite enhanced nitrogen availability, and crop growth in addition to minimizing the emission of methane from rice soils.** Due to the combined effect of growth enhancement and lesser methane flux, nitrogen loaded nano zeolite might be a potential and eco friendly source of N in rice cultivation.

6.2. Project at International Crop Research Institute for Semi Arid Tropics

Center of Excellence on Climate Change Research for Plant Protection

6.2.1. Objectives

- Predict and map potential changes in relative abundance and geographical distribution of insect-pests and diseases in grain legumes.
- Standardize techniques to study insect-pest/pathogen x host plant × environment interactions.
- Study biochemical, molecular and genetic interactions between pathogens/insect pests x host plant x environment in relation to expression of resistance to the target pests.
- Capacity building for undertaking research on the effect of climate change on crop protection.

6.2.2. Establishment of climate change facilities

Climate change facilities such as Open Top Chambers (OTC), Free Air Carbon Dioxide Enrichment (FACE), and CO_2 incubators with precise CO_2, temperature and relative humidity controlled incubators to undertake research on the interaction of host plant with the specific pests and pathogens were established at ICRISAT-Patencheru, Hyderabad. These facilities were established in addition to the existing facilities such as temperature and humidity controlled growth chambers and insect-rearing laboratory and other essential equipment's required to study the insect pest/pathogen × host plant × environment interactions at genetic, biochemical and molecular levels (Figure 3).

Climate change facilities established at ICRISAT, Patancheru, Hyderabad.

6.2.3. Results

i. Changes in disease and insect-pest spectrum over the past four decades

Pigeonpea diseases: Five diseases namely Phytophthora blight (*Phytophthora cajani*), sudden death (*Fusarium acuminatum*), alternaria blight (*Alternaria alternata* and *Alternaria tenuissima*), dry root rot (*Macrophomina phaseolina*) and collar rot (*Sclerotium rolfsii*) have been identified as emerging diseases in pigeonpea (Figure 1). The relative importance and frequency of occurrence of these diseases has significantly increased as compared to 1975-1980 reports.

Chickpea diseases: Dry root rot (*Rhizoctonia bataticola*) & collar rot (*Sclerotium rolfsii*) clearly emerged as serious diseases in chickpea as compared to Fusarium wilt more prevalent earlier. In addition trends of stunt, powdery mildew, scleotinia stem rot and colletotrichum blight have also been found in some region.

ii. Weather variables as predictor for diseases: Models were developed for forewarning amount of maximum disease severity, crop growth stage at first appearance of disease and crop age at peak severity for Phytophthora blight of pigeonpea taking into consideration past one decade data. As per model, disease appeared at 50-60 days old crop and maximum Phytophthora blight incidence was found at 80-90 days crop growth stage. Phytophthora blight incidence in pigeonpea had positive correlation with rainfall and maximum RH. The mean of monthly precipitation from June through October was found to be a better predictor for Phytophthora blight. Similarly, dry root rot, an emerging disease in chickpea had positive correlation with temperature and evaporation

Emerging diseases in pigeonpea(a) Phytophthora blight (*Phytophthora cajani*), (b) sudden death (*Fusarium acuminatum*), (c) Alternaria blight (*Alternaria alternata* and *Alternaria tenuissima*), (d) dry root rot (*Macrophomina phaseolina*)

Emerging diseases in chickpea as a result of climate change (a) dry root rot, (b) collar rot and (c) powdery mildew.

and negative correlation with maximum rainfall. The linear regression models clearly indicated that dry root rot is predisposed by rising temperature and reducing soil moisture

iii. **Changes in pest spectrum over the past 100 years:** Twelve new pests, and several pest outbreaks have been recorded on pigeonpea in India, of which cotton bollworm, *Helicoverpa armigera*, spotted pod borer, *Maruca vitrata*, and pod sucking bugs, *Clavigralla* spp. have at times resulted in complete crop loss. In chickpea, cyclonic storms in Nov - Dec have resulted in outbreaks of beet armyworm, *Spodopteraexigua* in southern India and other pests in other parts of India.

iv. **Effect of climatic conditions on pest incidence in chickpea &pigeonpea in field:** Egg laying and larval density of *H. armigera* and *M. vitrata* was maximum in the third planting (Aug - Sep), which corresponded to moderate temperatures (T_{max}29 °C and T_{min} 21 °C) and high RH (RH_{max} 91% and RH_{min} 71%). *H. armigera* incidence in chickpea was greater in the first planting than in the other plantings [corresponding to T_{max} 29.8 °C and T_{min} 14.7 °C; and RH_{max} (92.8% and RH_{min} 42.7%].

The incidence of *S. exigua* was maximum in the fourth sowing (3.2 larvae/5 plants) and lowest in the second sowing (0.19 larvae/5 plants).

v. **Techniques standardized to study host, pathogen, & environment interactions:**

Various methods and techniques have been standardized to study the effect of climate change variables on pests and diseases.

- An ITS and LAMP based technology developed for rapid diagnostics of several pathogens such as *R. bataticola, S. rolfsii* infecting chickpea and *P. cajani, A. tenuissima, A. alternate, F. acuminatum* infecting pigeonpea.
- Developed controlled environment and mini-sick plot screening techniques to evaluate Phytophthora blight in pigeonpea against range of temperature, humidity and CO_2 and identification of resistant sources.
- Standardized Real time PCR technique to quantify the fungal pathogen colonization under various climatic conditions.
- Standardized controlled environment method for dry root rot for studying effect of high temperature and soil moisture levels on dry root rot pathogen (*R. bataticola*) survival and development and identification of resistant sources.

- Developed detached leaf assay, and diet impregnation assay to evaluate the effects of changes in biochemical composition of the host plant on feeding, survival, development and fecundity of *H. armigera* and *S. exigua*.
- Standardized real-time polyphenol-meter, HPLC and GC-MS techniques to evaluate quantative changes in secondary metabolites in chickpea and pigeonpea (Fig. 4).

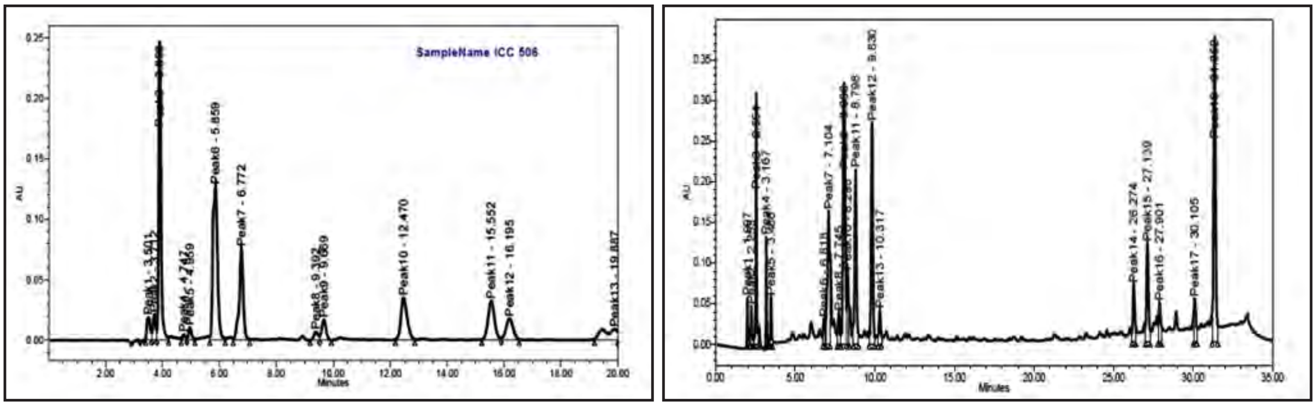


Fig. 5. HPLC chromatograms for flavonoids (a) in pigeonpea (b) in chickpea.

- Pigeonpea plants raised under normal conditions in the greenhouse exhibited *H. armigera* leaf damage rating of 5.8 to 7.6, while in plants raised under water and heat stress suffered a leaf DR of 1.0 to 3.3. Water and heat stress rendered the plants less suitable for growth and development of *H. armigera*.
- Chickpea plants grown under greenhouse conditions suffered a leaf DR 4.3 to 8.0 as compared to 2.8 – 4.5 in the plants raised under heat and water stress.

vi. Biochemical, molecular and genetic interactions between pathogens/ insect pests × host plant × environment in relation to expression of resistance to the target insect pests

- Significant changes in expression of enzymes viz. PAL, PO, PPO and CAT in Phytophthora blight challenged plants at different temperature was recorded. At lower temperature, no significant difference was observed.
- No significant effect of elevated $CO_2$was found on Fusarium wilt of pigeonpea. Phytophthora blight incidence and activity of APX, CAT, GR, GPX found increased under elevated CO_2. Sterility mosaic disease (SMD) also showed increased severity under elevated CO_2 (550 and 700 PPM). In response to elevated CO_2, chlorophyll content had increased significantly in both SMD infected and non-infected plants in comparison to ambient condition.
- Development of *R. bataticola* causing dry root rot of chickpea was positively correlated with temperature and soil moisture content 60%. Elevated CO_2 had no significant role on dry root rot incidence.
- Elevated CO_2 (550 and 700 PPM)advanced the appearance of Fusarium wilt as compared to ambient. Under elevated CO_2, APX and GPX activities decreased in compatible and increased in the incompatible interaction. Under elevated CO_2, CAT activity decreased in compatible and increased in the incompatible interaction.

- The chlorophyll and flavonol contents increased in pigeonpea plants in response to water and heat stress, however, the differences were not statistically significant.
- Carbohydrate content was greater in plants grown under water and heat stress as compared to the plants raised under normal conditions. However, there were no differences in protein content between the plants raised under normal and stress conditions.
- In BOD incubators, there was no survival of *S. exigua* at 15 and 45^{0}C. The survival of S. exigua larvae decreased at 95% RH as compared to that at 50% RH.
- The weights of *H. armigera* larvae increased, but the survival period decreased with an increase in temperature from 15 – 35^{o}C. No *H. armigra* larvae survived at 45^{o}C.
- The *H. armigera* larval and pupal weights decreased, but pupation, adult emergence and fecundity increased with an increase in RH from 25 – 75% RH. Weights of *H. armigera* larvae decreased, fecundity increased with an increase in CO_2 levels. Leaf feeding increased, but the larval survival decreased with an increase in CO_2.
- Amino-peptidase activity had decreased in *H. armigera* larvae fed on plants grown under elevated CO_2 than the larvae fed on plants grown under ambient conditions, but the amylase activity and carbohydrate levels increased with an increase in CO_2 levels.

6.2.4. Strategic knowledge generated

- The severity of diseases (Phytophthora blight and sterility mosaic in pigeonpea, and root rots in chickpea) and insect pests (*Maruca* and *Helicoverpa* in pigeonpea, and *Spodopteraexigua* in chickpea) will increase as a result of global warming and climate change. New diseases (Alternaria blight in pigeonpea& chickpea and sudden death and root rots in pigeonpea), and insect pests (leaf miner and mealy bugs, *Planococcus* and *Ceroplastodes*in pigeonpea, and white fly, *Bemisiatabaci* and mealy bug, *Planococcus*in chickpea) are likely to emerge as serious pests under elevated temperature and CO_2. This information can be used to develop strategies for pest management in these crops to mitigate the effects of climate change for sustainable production of grain legumes.
- High temperature and drought predispose chickpea to dry root rot; while high rainfall with-in a short span of time results in outbreaks of Phytophthora blight in pigeonpea. Cyclonic storms in October result in outbreaks of beet armyworm, S*podopteraexigua* in chickpea, and *Helicoverpa* and *Maruca* in pigeonpea in southern India; while temperatures >5^{o}C than normal in March result in heavy losses due to *Helicoverpa* in chickpea and pigeonpea in North India. This information can be used to issue appropriate advice to the farmers to take timely disease/pest control measures to minimize the effects of climatic conditions that may lead to pest outbreaks.
- Identified disease-resistant (ICCV 05530, ICCV 08318, ICC 11322 in chickpea and ICPL 99050, MN1 in pigeonpea) and pest-resistant (ICPL 332WR and ICPHaRL 4989-7 in pigeonpea and ICCV 10 in chickpea) varieties that have stable resistance across environments can be used for cultivation by the farmers *per se* or use them for developing pest and climate resilient cultivars for sustainable crop production.
- Identified secondary metabolites and defensive enzymes that could be used as indicators of the effects of climate change on expression of resistance to diseases and pests. Aminopeptidase (a receptor for Bt toxins) activity decreases under elevated CO_2, suggesting decreased effectiveness of

Bt-transgenic crops for pest management in future. This information will be useful for developing disease and pest –resistant cultivars to mitigate the effects of climate change.

Knowledge sharing and capacity building activities in climate change research forplant protection at ICRISAT.

6.3. Project at Indian Agricultural Research Institute

Adaptation of Indian agriculture to climate change

6.3.1. Objectives

1. To develop adaptation technologies to enhance the resilience of agriculture to the current and future climatic risks.
2. To update simulation models for assessing impact of climate change and adaptation strategies.

6.3.2. Results

i. **Screening of genotypes of wheat for climate change adaptation:** Four promising wheat cultivars of short (WR 544 and HD 2285), medium (HD 2932) and long (HD 2967) growth duration were grown from October to January at 15 days interval to expose the crop to high thermal stresses All the wheat cultivars irrespective of their growth duration registered poor yield when subjected to initial and terminal heat stresses. Among the cultivars, the medium and long duration wheat cultivars (HD 2932 and HD 2967) invariably recorded higher yield both under normal as well as under early and late sown conditions, whereas the short duration cv. HD 2285 performed well under extreme late sown condition. Reduction in yield by initial heat stress was mainly attributed to marked reduction in spikes/m^2, while terminal heat stress caused drastic reduction in yield mainly by reducing the growth duration, grains/spike and 1000 grain weight. Both initial and terminal heat stresses hastened flowering in all the cultivars, while, total days to maturity reduced gradually with delayed sowing. It is concluded that short duration cultivars may be suitable only for late sowing, while long duration cultivars may perform better both under early and late sown condition especially under mild terminal heat stress condition (Fig. 1).

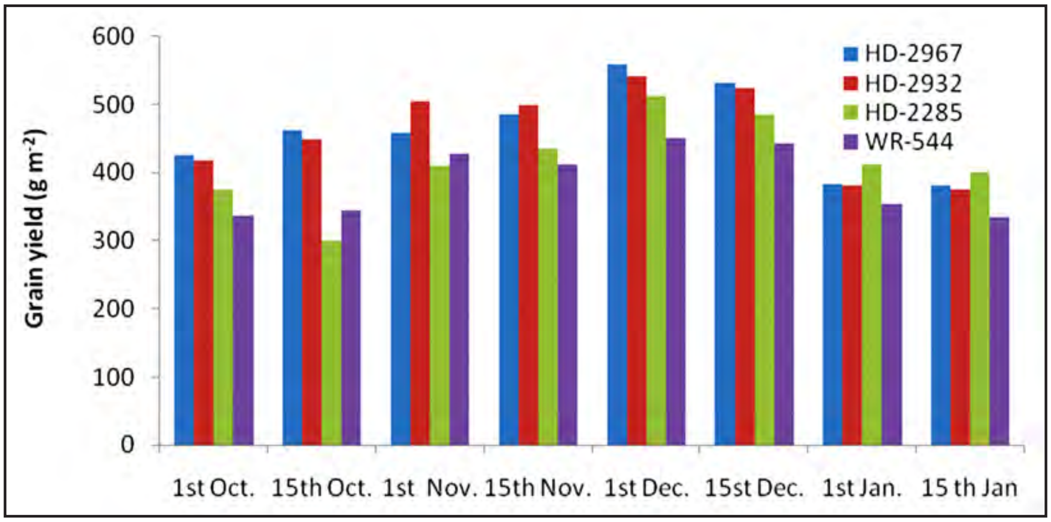


Fig. 6. Effect of initial and terminal heat stress on yield of wheat cultivars.

ii. **Evaluation of maize genotype for biotic stress tolerance:** 183 lines of maize were screened against Maydis Leaf Blight (MLB) and Banded Leaf and Sheath Blight (BSLB). Based on the rating (scores in the scale of 1-5; 1-highly resistant and 5-highly susceptible), under artificial inoculation conditions, 13 (for MLB) and 16 (for BLSB) genotypes were selected. Full details regarding the following selected genotypes found resistant/tolerant to MLB/BSLB are tabulated below. More importantly, three lines showed resistance to both MLB and BSLB (viz., 130092, 130098, 130158).

Table 5.Maize genotypes tolerant to various biotic stresses.

S. No.	Genotypes tolerant against MLB	Score against MLB	S. No .	Genotypes tolerant against BSLB	Score against MLB
1	130006	2	1	130019	2.5
2	130007	2	2	130024	2.5
3	130008	2	3	130092	2.0
4	130044	2	4	130098	2.5

5	130048	2	5	130102	2.5
6	130052	2	6	130116	2.5
7	130053	1.5	7	130117	2.5
8	130082	2	8	130132	2.5
9	130092	2	9	130137	2.5
10	130094	2	10	130150	2.5
11	130098	2	11	130154	2.5
12	130158	2	12	130155	2.5
13	130174	2	13	130158	2.0
			14	130169	2.5
			15	130179	2.5
			16	130181	2.5

iii. **Evaluation of maize genotype for cold tolerance:** One hundred genotypes of maize were screened against cold stress and 10 were found tolerant to cold stress. Selected 10 genotype of maize were shown in field for re-screening against cold stress and observations such as leaf color (green, pale green, purple, yellow), number of leaves/plant, leaf on which symptoms are present, location of symptoms (Symptoms on centre or on margins), type of leaves (broad or narrow), plant vigour, date of silking, date of tasseling and plant height were recorded. The study will continue to identify the tolerant genotypes and include them in the breeding programme.

iv. **Evaluation of maize genotypes for high temperature tolerance:** From a very large plot of maize composite PC-4 production individual plants were selected on the basis of standard features. Selected 6lines of maize were planted in IARI field in spring season (2014) (sowing in second week of March, flowering during first week of May -2014, for recording the response under high temperature. Some biochemical parameters (total antioxidants, catalase, peroxidase) were assayed to differentiate between tolerant and susceptible lines. Total antioxidants were high in tolerant lines in comparison to susceptible lines. Similarly, peroxidase and catalase activity (to scavenge free radicals generated during stress conditions) also showed high values in tolerant lines in comparison to susceptible lines. The maize genotypes in each of the tolerant and susceptible group are further being advanced for more detailed analysis.

v. **Biochemical traits for climatic stress tolerance:** Identified few differentially expressed proteins such as HSP17, oxygen evolving enhancer proteins, HSP26, superoxide dismutase, rubiscoactivase, calcium dependent protein kinase and calcium binding protein in wheat under the heat stress. The magnitude of accumulation/activity of these proteins can be used as one of the criteria to identify lines with high tolerance to the abiotic stresses; can be extended to other crops as well.

vi. **Screening of wheat germplasm for proline accumulation:** Proline accumulation has been considered as one of the most important trait for protecting the internal metabolic system under drought and heat stress. Seventy three different wheat lines grown under net-house were used for the proline estimation at grain filling stage (samples were collected based on the Feeke scale). Maximum proline accumulation was observed in C306, Kundan and Halna, whereas minimum was observed in UP2648 and UP2647. Most of the thermotolerant lines were observed to be good proline accumulator, whereas thermosusceptible lines showed very low accumulation of proline (Fig. 1).

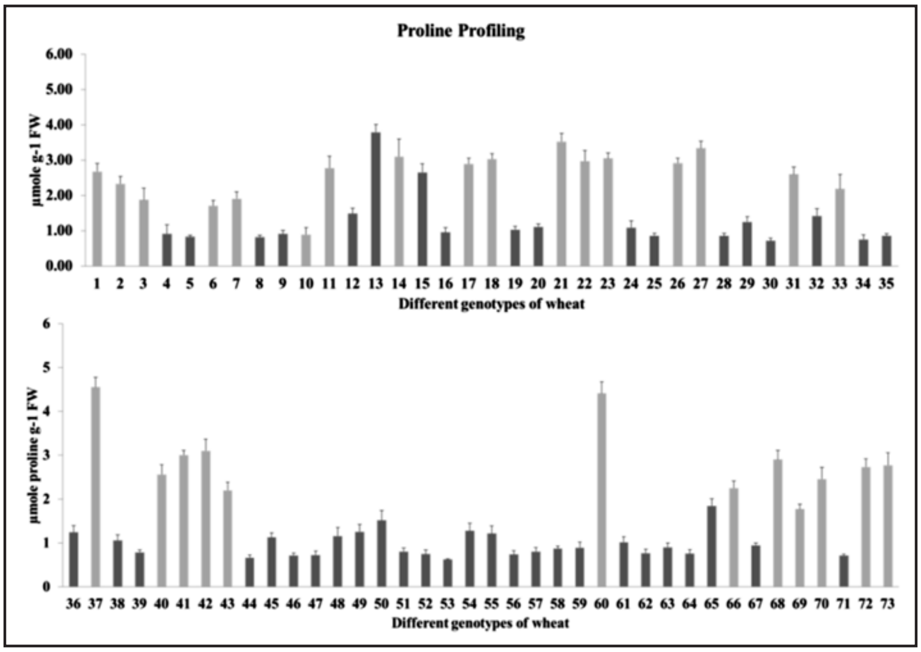


Fig. 7.Proline profile of different wheat genotypes.

vii. **Screening of wheat germplasm for total antioxidant capacity:** Total antioxidant capacity (TAC) has been selected as one of the most promising parameters for screening wheat germplasm for thermo-tolerance. Studied the variations in the TAC in 73 different wheat germplasmgrown under net-house condition at grain-filling stage (selected based on Feeke scale). HD 2781 showed maximum TAC value followed by HD 3059 and HD 3090. The TAC was observed minimum in K 9423 followed by UP 2338 and UP 2748. Most of the cultivars which showed high yield under terminal HS showed high TAC value compared to cultivars sensitive to HS where there was low value of TAC. To conclude, cultivars having high proline accumulation and TAC value had high thermotolerance capacity and withstand the terminal HS during grain-filling stage without compromising with the yield (Fig. 4).

viii. **Up-gradation of InfoCrop simulation model:** The InfoCrop generic simulation model has been upgraded (InfoCrop 2) with updated models and new interface to make it a multi-utility model.

The entire interface of the InfoCrop is reconstructed and the weather conversion module is made more powerful which can handle large number of files at a time to convert to the input file format for running the dynamic simulation model. The InfoCrop 2 has updated models (updated temperature and CO_2 responses), and is compatible to new operating system with improved weather conversion tool, batch processing module, new models of wheat, maize, sorghum, soybean and potato and a user manual.

ix. **Modelling pest and disease management for adaptation to climate change:** Thermal constant based population simulation model for tobacco caterpillar, *Spodoptera litura* was developed using bio-ecological parameters, such as, sex ratio, fecundity, and biotic and abiotic mortality factors. Simulated and observed development periods of the pest stages, and generation times (38 and 37 days, resp.) were in close agreement.

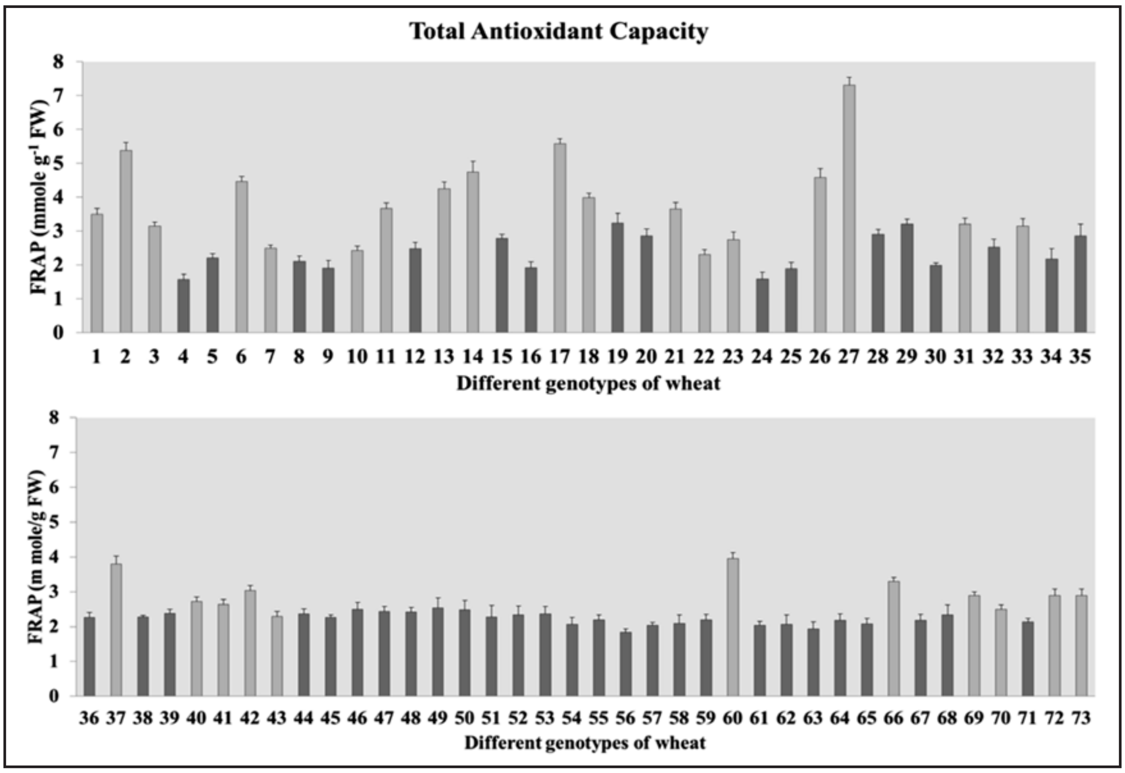


Fig. 8.Antioxidant capacity of different wheat genotypes.

Simulated and observed increase in larval population over a generation was 3.3 and 2.8 times, respectively. Simulation model could thus simulate life cycle of the pest satisfactorily. The model will facilitate assessment of climate change impact on pest population and pest forewarning. In aftermath of two outbreaks of brown plant hopper (BPH) in 2008 and 2013, analysis of 1998-2013 weather data revealed that good pre-monsoon rain in June followed by more frequent rains i.e., more number of rainy days (46-49 days during 2008 & 2013; 27-42 days during non-outbreak years) that led to higher relative humidity might favour fast multiplication of BPH, thus playing a role in its outbreak. This information would be useful in forewarning of the BPH outbreak.

Aphid incidence on three wheat cultivars, HD2967, HD2985 and WR544, was observed under three sowing dates. Wheat sown on 6thDecember had significantly more aphids (52.4/5 earheads) compared to the crop sown between 16thand 26thDecember. The cultivars, however, did not differ with regard to aphid incidence. Effect of crop phenology on aphid incidence becomes important in view of changes in sowing time that may occur under climate change.

x. **Assessing the impacts of climate change on insects:** Elevated CO_2 (570 ±25 ppm) enhanced BPH multiplication (72.7±16.2 hoppers/hill) compared to ambient CO_2 (32.6±4.7 hoppers/hill). Higher BPH population due to greater fecundity under elevated CO_2 resulted in higher yield loss (26.5%) than ambient CO_2 (12.4%). The sucking rate of the BPH was also higher under elevated CO_2. In aftermath of two outbreaks of brown plant hopper (BPH) in 2008 and 2013, analysis of 1998-2013 weather data revealed that good pre-monsoon rain in June followed by more frequent rains i.e., more number of rainy days (46-49 days during 2008 & 2013; 27-42 days during non-outbreak years) that led to higher relative humidity might favour fast multiplication of BPH, thus playing a role in its outbreak. This information would be useful in forewarning of the BPH outbreak. Peaks of leaf folder light trap catches during 5 years (2008-2012) at Ludhiana (Punjab) showed significant relationship with maximum temperature (Tmax), morning relative humidity (RH_1), evening relative humidity (RH_2) and sunshine hours (SSH) of 28th Standard Meteorological Week (SMW).

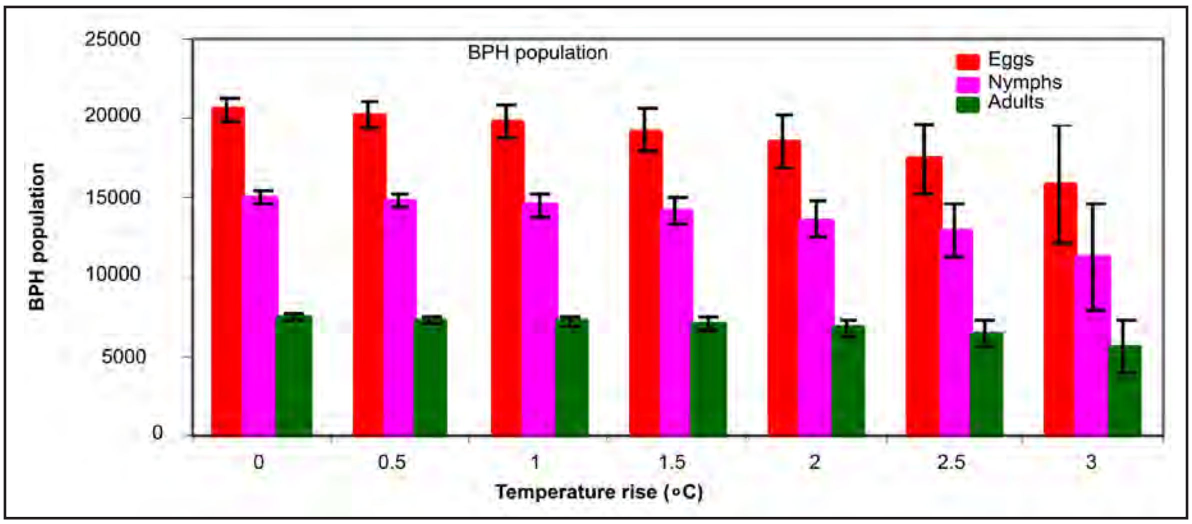


Fig. 9.Simulation of Brown Plant hopper (BPH) population with increased temperature.

Weather-based prediction model was developed and validated. The leaf folder having become an important pest in recent years, calls for forewarning and regular monitoring of its incidence under climate change. Among three transplanting dates, leaf folder had more incidence in early transplanted Pusa 1401, while whorl maggot preferred most the late transplanted crop. On the other hand, plant hoppers were more on timely transplanted crop (213.6/hill). Pusa Basmati 1509, a short duration cultivar, escaped BPH attack during *kharif* 2013, while varieties such as Pusa Basmati 1121 suffered heavily. Such varieties will become important from pest management point of view under climate change. The BPH population simulation model was developed based on thermal constant, threshold of development, and abiotic and biotic mortality factors and coupled to InfoCrop model. 0.5 to 3.0 ºC rise in *kharif* showed 1.5 to 25.2% population decline. In climate change scenario 2020 (0.87-1.17 ºC rise), BPH population declined by 3-4% and in 2050 (1.81-2.37 ºC rise) it declined by 9-14% (Fig. 4).

xi. **Simulating impacts of climate change on crop productivity:** A simulation analysis was done to assess the impacts of climate change on rice, wheat, mustard and potato crops in the IGP region. The adaptation gains and vulnerable regions also are derived. The analysis was done using MIROC and PRECIS scenarios and the InfoCrop model for three time slices (2020 -2010-2039; 2050-2040-2069; 2080-2070-2099).

   a. **Wheat:** The results indicated that among the wheat-growing regions, the impact of climate change on yield is projected to vary spatially, and with climate and emission scenario. By 2050, wheat yield in north-western IGP (NWIGP), consisting of the states of Punjab and Haryana, is projected to decrease 8 to 22%, with a greater reduction in Haryana. The initial gains in productivity due to climate change in this region may taper at a later period of this century. In the central IGP (CIGP) region, yield in Uttar Pradesh (UP) is projected to be reduced by ~24%. A similar yield reduction is projected for West Bengal in eastern IGP (EIGP). In the IGP region, climate change impact on wheat yield is projected to be more in Haryana, Uttar Pradesh, Bihar and West Bengal. Yield reduction is projected to be less in areas with current mean seasonal minimum temperatures of 10 to 12°C than those having >12°C, such as in parts of EIGP. In various emission scenarios, projected increase in mean seasonal minimum temperatures in these regions is by ~1.5”2°C in 2020, ~2.5”4°C in 2050 and 4”6.5°C in 2080. Even though a similar or slightly higher increase in temperature is projected for the NWIGP region, the projected impacts are less, due to current lower mean seasonal minimum temperatures of ~7 to 10°C. Seasonal mean maximum temperatures in wheat growing areas in India also vary significantly from 23”25°C in the NWIGP to 29”30°C in the EIGP region. Adjusting the time of sowing within the timely-, late- and very late- sowing windows is projected to minimize yield reduction even with existing varieties under improved nutrient and irrigation management and with higher dose of nitrogen fertilizer (25% higher than the dose currently applied by farmers). In order to sustain the yield in future, timely sowing of improved wheat varieties across IGP along with better management (nutrients and irrigation) and application of higher dose of nitrogen fertilizer is essential. By doing so, the impacts can be offset up to 2050. Even if all the above mentioned strategies are employed together, the wheat production in India by 2080 is projected to still reduce by ~5% (Naresh Kumar et al., 2014a).

   b. **Rice:** At regional level, states like Punjab, Haryana and Rajasthan are projected to lose more yields (6–8 %) in the 2020 scenario. Similarly in the 2050 scenario, projected yield loss is expected to stand at 15–17 % in the above three states More reduction in irrigated rice yields have been projected for areas with current seasonal (June-September) mean minimum temperatures of >23 °C, as in parts of north (Uttar Pradesh, Bihar and Jharkhand) and northeast regions of India. The temperatures are projected to increase which may cause heat stress on crop. Projected rise in temperatures for north western India are even higher (1.8–2.8 °C in 2020 scenario); and therefore, future temperatures constrain higher productivity of irrigated rice in these areas. The results indicate that the impact of climate change on irrigated rice can be offset with either agronomical management or with improved varieties in shorter periods (the 2020 scenario);

but in the longer periods (2050 and 2080 scenarios), growing improved varieties, coupled with efficient crop management, will become essential to enhance productivity for meeting increased demand. Regions that are adversely affected can have net improvement in yield in future scenarios with adaptation (most of irrigated rice areas of west and north India) (Naresh Kumar et al., 2013).

c. **Mustard:** At the regional level, states like Punjab and Haryana are projected to have increased yield in 2020. In other parts of north India (Uttar Pradesh, Bihar and Assam), yields are projected to reduce up to 6%. Projected yield reduction in north India is 0.5–4% in 2020, 3–10% in 2050 and 12–23% in 2080. A combination of improved input efficiency, 25% additional N, and adjusting the sowing time can increase the yields by ~17% with current varieties and by ~25% with improved varieties in 2020. These benefits are projected to progressively reduce beyond 2020 (Naresh Kumar et al., 2014b).

d. **Potato:** The potato crop duration in the IGP is projected to decrease due to climate change. The evapotranspiration (ET) is projected to increase while the water use efficiency‘(WUE) for potato yield is projected to decline in future climates as a consequence of low threshold temperatures for decline in WUE and yield than the ET. Results indicate that the upper threshold for ET decrease is ~23 ^{o}C while that for WUE is 15 ^{o}C. The optimal temperature for tuber yield is ~17 ^{o}C and thus the reduction in WUE in future climates is discernable. Climate change is projected to reduce potato yields by ~2.5, ~6 and ~11% in the IGP region in 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099) time periods.

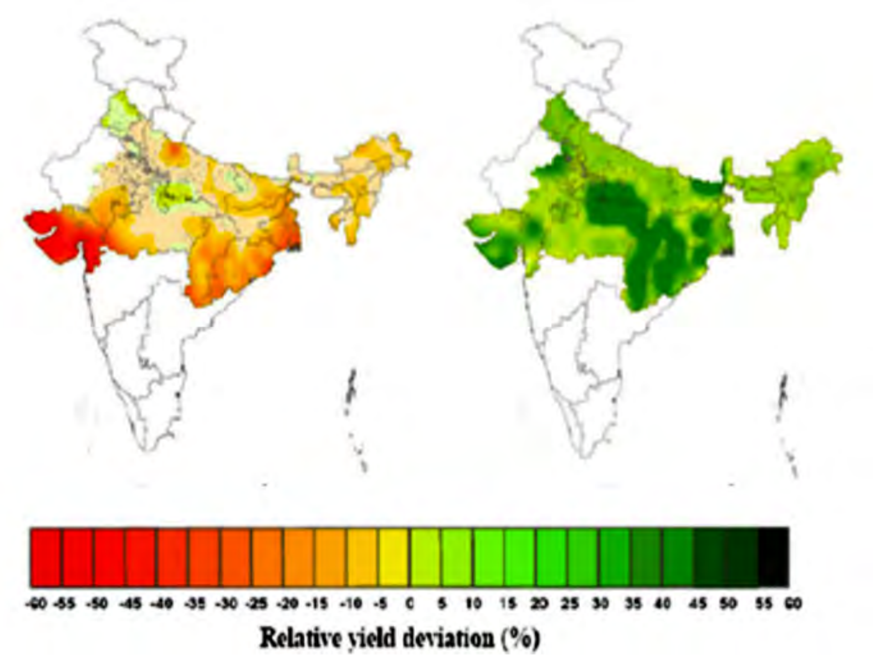


Fig. 10. Impact of climate change on mustard yield (a) and adaptation gains (b) in 2020 scenario.

Change in planting time is the single most important adaptation option which may lead to yield gains by ~6% in2020 and its combination with improved variety or additional nitrogen may be required to adapt to climate change leading to positive gains by ~8% in 2020 and by ~5% even in 2050. However, in 2080 adoption of all the three adaptation strategies may be needed for positive gains. Intra-regional differences in the impact of climate change and adaptation gains are projected; positive impact in northwestern IGP, gains in Central IGP with adaptation and yield loss in eastern IGP even with adaptation (Naresh Kumar et al., 2015).

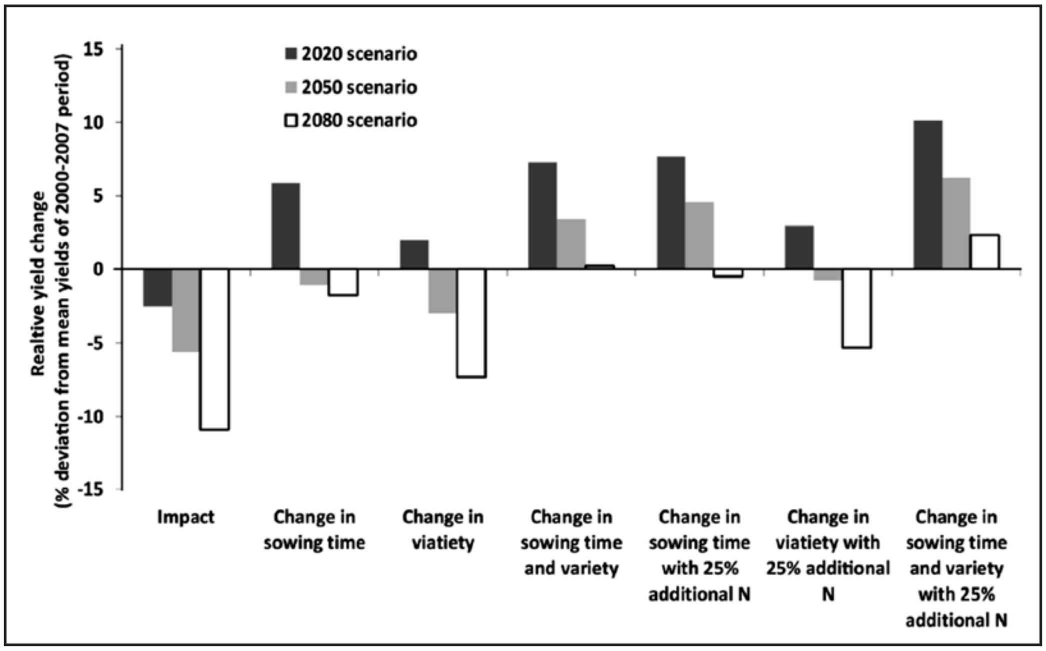


Fig. 11. Impact of climate change on potato yield and adaptation gains in 2020, 2050, 2080 scenario.

xii. **Crop growth monitoring system:** Developed a web-enabled Decision Support system (DSS) for real time crop growth monitoring at district level using multi-temporal satellite remote sensing data received at IARI satellite ground station. The DSS was hosted on public website http://creams.iari.res.in. Satellite derived weekly Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI) and Daily Rainfall products were generated for crop pixels and averaged in each district for a period of 2001-2013 (Fig. 5). A web-interface was created in PHP, WYSIWYG and HTML which allowed for selection of State from India map and then selection of district. The interface provided selection of parameter (rainfall, LST and NDVI), season (*Kharif or Rabi*) and year. This web-interface was linked to database of parameters which fetched the related data of current season and compared it with parameter of same season in previous year and with long-term average. The temporal profile of parameter of current year and its comparison with that of previous year and long term average was visualized graphically as well as in tabular format. The anomaly in parameter for current period from long term average was also computed, then categorized into five classes and visualized as a map. A web-interface allows selection of maps for different weeks/fortnight. The parameter database were kept updated with new real time data as it became available. The system was used to monitor the wheat crop condition in response to terminal heat stress during Feb-March 2013 and crop condition across India during *Kharif* and *Rabi* seasons of 2013-14.

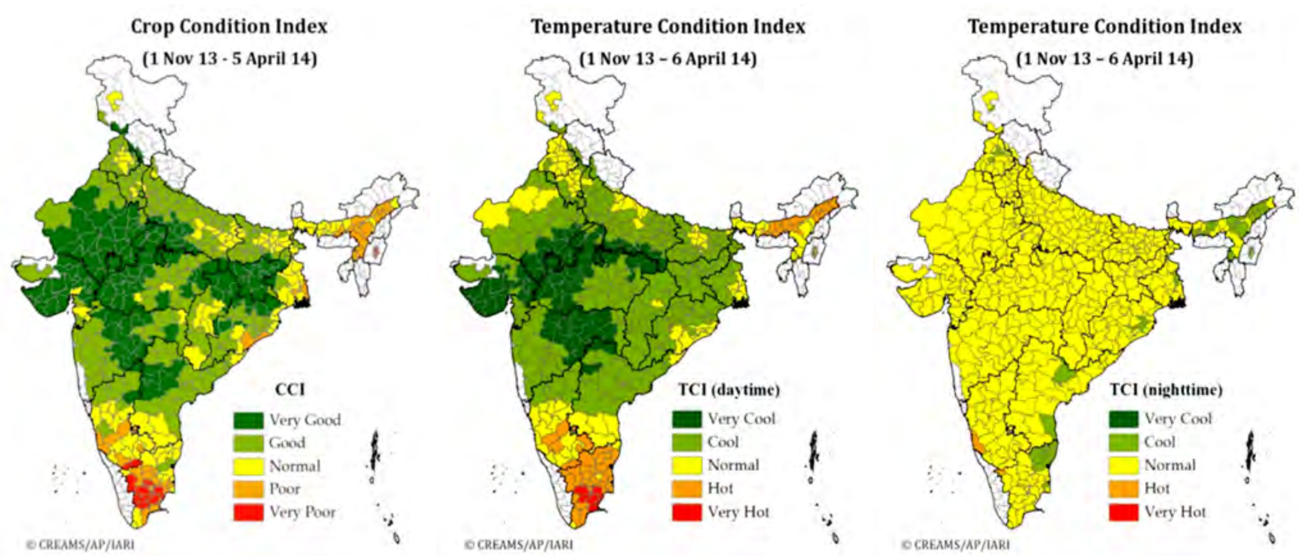


Fig. 12. Crop condition index and temperature condition index for day and night maps for rabi 2013-14.

xiii. **Conservation agriculture for improving resource-use efficiency and productivity in rice-based cropping system:** Direct-Seeded Rice (DSR) with mungbean residue incorporation, Brown Manuring (BM) with *dhaincha* (*Sesbania aculeata*), Rice Residue (RR) retention in Zero Till (ZT) wheat or in other winter crops are important Conservation Agriculture (CA) practices, which can lead to sustain productivity in north-western plains zone of India, besides, mitigating Greenhouse Gases (GHGs) emission and enhancing carbon sequestration in soil. Therefore, in a field study, comparison was made on the performance of DSR cv. 'PRH 10' with different CA practices with Conventional Transplanted Puddled Rice (TPR). It was observed that DSR with Summer MungBean (SMB) residues incorporated and Rice Residues (RR) retained on the surface in Zero-Till Wheat (ZTW), followed by summer mungbean (SMB) gave rice yield similar with, but wheat yield higher than TPR- CTW or ZTW. It gave higher system crop productivity, net returns, B:C ratio, water productivity, and energy-use efficiency than that of TPR-CTW or ZTW. It also resulted in a considerable improvement of Walkley and Black carbon, labile and very labile carbon, and total N content in the surface (0-5 cm) soils in rice-wheat system. This treatment and other DSR treatments showed a considerable reduction in global warming potential (GWP) through reduction of methane emission from rice field.

xiv. **Conservation agriculture for improving resource-use efficiency and productivity in wheat-based cropping systems:** Conservation Agriculture (CA) practices for three non-rice crop (cotton, pigeonpea, maize)-based cropping systems under irrigated conditions was studied with a view to replace rice with suitable alternative crops during *kharif* season in north-western plains zone and to diversify the rice-wheat system. Three major non-rice cropping systems, *viz*., maize-wheat, cotton-wheat, pigeonpea-wheat were studied with different CA practices. Among the *kharif* crops, cotton was superior to pigeonpea and maize, and among the cropping systems, cotton-wheat system was consistently superior to pigeonpea-wheat and maize-wheat systems over the years in terms of crop yield, system productivity and net returns. Cotton-wheat system under zero-till broad bed with residues gave higher system crop productivity, water productivity, energy productivity & efficiency and net returns than pigeonpea-wheat or maize-wheat system. This CA practice resulted in significantly higher Soil Organic Carbon (SOC), particularly at the surface (0-5 cm) layers in soil. Cotton-wheat system out-yields rice-wheat system, has less GHGs emissions, higher water- and energy-use efficiency, and could be a potential alternative to rice-wheat system. This could be an adaptation strategy for mitigating climate change effects *vis-à-vis* for sustaining crop production.

6.3.3. Strategic knowledge generated

- Genotypes of rice, wheat and maize for tolerance to temperature and resistance to pests and diseases were identified and evaluated.
- Identified few differentially expressed proteins such as HSP17, oxygen evolving enhancer proteins, HSP26, superoxide dismutase, rubiscoactivase, calcium dependent protein kinase and calcium binding protein in wheat under the heat stress. The magnitude of accumulation/activity of these proteins can be used as one of the criteria to identify lines with high tolerance to the abiotic stresses; can be extended to other crops as well. Based on the biochemical traits, one can easily predict the tolerance nature of the cultivar under the climatic variations.
- InfoCrop model was updated for assessing the effect of climate change on crop yields and development of adaptation strategies.
- Conservation agriculture practices such as direct seeded rice with or without sesbania brown manuring, rice residues mulch in wheat and summer mungbean grown for grains and stover incorporated as green manure have been evaluated for adaptation to climate change.
- Greenhouse gas emissions from Indian agriculture were assessed and the trends in emission were analyzed.
- Agriculture offers promising opportunities for mitigating GHGs emissions largely through carbon sequestration, soil and land use management, and biomass production. Various adaptation technologies for climate change and their co-benefits in terms of GHGs mitigation were identified and assessed.
- Existing knowledge on climate change adaptation available in various institutes and universities in the country was collated and analyzed. This will help in developing strategic knowledge for climate change adaptation and can be implemented by the farmers.

7. Conclusion

Climate change effects on agriculture are likely to be ubiquitous, both in terms of direct and indirect impacts. Maintaining plant health across the planet, in turn, is a key requirement for climate change mitigation, as well as the conservation of biodiversity and the provision of ecosystem services under global change. Information gathered so far has been fragmented and a comprehensive analysis of climate change impacts on agriculture is required. Experimental research on a diverse range of crop and biotic and abiotic systems is necessary to improve comprehension of climate change impacts on agriculture. To maintain ecosystem health and services under variable, unpredictable or unknown conditions, we need more resilient systems, decentralization, participatory research and breeding networks. At the same time, increased involvement of the many stakeholders and scientists from outside plant pathology shows the importance of considering trade-offs with other objectives. Increasing diversity would be in favour of a land-sharing approach, but may be relevant also to land-sparing scenarios (e.g. at the margin of fields), depending on the spatial and temporal scale and the type of diversity (genetic, species, species turnover, ecosystem) considered.

8. Way Forward

Concerted efforts are required for development of mitigation and adaptation strategies to climate change so as to increase resilience and reduce vulnerability of Indian agriculture at local, regional and national scales. As climate change impacts has no boundaries, research collaboration between developed and developing countries with funding support should be promoted and strengthened for developing and transferring climate-smart technologies. Development and operationalization of adaptation strategy necessitate socio-psychological empowerment of farmers besides developing competencies in acquiring knowledge and skills related to adaptation practices.

Research on the likely patterns of change in plant diseases and insect-pests attributable to predicted climate change is important. There is a need for better understanding of historical data on incidence and severity of diseases/ insect-pests in relation to changes in cropping patterns and climatic conditions. Research should seek to understand the interaction between drivers of diseases/ insect-pests and environmental changes. Moreover a holistic hotspot analysis of environmentally induced diseases is important to comprehend the interacting drivers of emerging diseases, adaptation processes as well as the role of vulnerability in disease patterns.

To face the challenges of food security and climate change, the country needs to reorient its land use and agriculture with the state-of-the-art technologies and policy initiatives. Impact of climate change on gender is another area that need to be concentrated. Cost on adaptation and economics need to be worked out for the future climate under business as usual condition and for changed management situation for up-scaling adaptation options to larger regions. 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.

9. References

1. Pande S and Sharma M (2009) Effect of climate change on the diseases of food legumes in Semi-Arid Tropics: Retrospect and prospect. [Abstract] Page 11 *in* 5th International Conference on Plant Pathology in the Globalization Era, Nov. 10-13, 2009, Indian Phytopathological Society,Indian Council of Agricultural Research, New Delhi, India
2. Pande S, Sharma M, Naga Mangala U, RajuGhosh andSundaresan G (2011)Phytophthora blight of Pigeonpea [Cajanuscajan (L.) Millsp.]: An updating review of biology, pathogenicity and disease management. Crop Protection 30: 951-957.
3. Sharma M and Pande S (2013) Unravelling effects of temperature and soil moisture stress response on development of dry root rot [*Rhizoctoniabataticola* (Taub.)] Butler in Chickpea. Am J Plant Sci 4: 584-589.
4. Sharma M, Ghosh R and Pande S (2013) Occurrence of Alternariaalternata causing Alternaria blight in pigeonpea in India. AdvBiosci Biotech 4: 702-705.
5. Sharma HC(2005)*Heliothis*/*Helicoverpa* Management: Emerging Trends and Strategies for Future Research. New Delhi, India: Oxford & IBH and Science Publishers, USA. 469 pp.
6. Sharma HC (2010) Effect of climate change on IPM in grain legumes. In: 5th International Food Legumes Research Conference (IFLRC V), and the 7th European Conference on Grain Legumes (AEP VII), 26–30April 2010, Anatalaya, Turkey.
7. Sharma HC and Ortiz R(2000)Transgenics, pest management and the environment.CurrSci 79: 421-437.
8. Sharma HC, Sullivan DJ andBhatnagar VS(2002) Population dynamics and natural mortality factors of the Oriental armyworm, *Mythimnaseparata* (Walker) (Lepidoptera: Noctuidae) in South-Central India. Crop Protection 21: 721-732.

10. Research Publications Emanated from Programmes

10.1 TNAU, Coimbatore

1. Bhuvaneswari K, Geethalakshmi V and Lakshmanan A (2013) Impact of climate change on hydrology of Cauvery basin. Madras Agric J 100(10-12) (Accepted).
2. Bhuvaneswari K, Geethalakshmi V, Lakshmanan A and Anbhazhagan R (2013) Crop Weather Model: An effective tool for assessing the impacts of climate change and developing adaptation strategies in rice. J Agrometeo 16(1): 38-43.
3. Bhuvaneswari K, Geethalakshmi V, Lakshmanan A and Anbhazhagan R (2013) Study of ENSO effects on hydrology and rice productivity in Cauvery basin using SWAT. Weather Climate Extremes 2: 39-47.

10.2 ICRISAT, Hyderabad

Papers in journals

1. Ghosh R, Sharma M, Telangre R and Pande S (2013) Occurrence and distribution of chickpea diseases in Central and Southern parts of India. American J Plant Sci 4:940-944.
2. Sharma M, Ghosh R and Pande S (2013) Occurrence of *Alternariaalternata*causing Alternaria blight in pigeonpea in India. AdvBiosci Biotech 4:702-705.
3. Sharma M, Ghosh R, Telangere R, Senthilraja G and Pande S (2013) First report of *Fusariumacuminatum*on Pigeonpea in India. Plant Diseasehttp://dx.doi.org/10.1094/PDIS-06-13-0586-PDN.
4. Sharma M, KiranBabu T, Gaur PM, Ghosh R, Rameshwar T, Chaudhary RG, Upadhyay JP, Om Gupta, Saxena DR, Kaur L, Dubey SC, Anandani VP, Harer PN, Rathore A and Pande S (2012) Identification and multi-environment validation of resistance to *Fusarium oxysporum* f. sp. *ciceris* in chickpea. Field Crops Res135:82–88.
5. Sharma M, Ghosh R, Sharma TR and Pande S (2012) Intra population diversity in *Rhizocotonia bataticola* causing dry root rot of chickpea (*Cicer arietinum*L.) in India. African J Microbiol Res 6(37): 6653-6660.
6. Sharma M, Ghosh R, Krishnan RR, Mangala UN, Chamarthi S, Varshney RK and Pande S (2012) Molecular and morphological diversity in *Rhizoctonia bataticola* isolates causing dry root rot of chickpea (*Cicerarietinum* L.) in India. African J Biotech 11(37): 8948-8959.
7. Vadez V, Ratnakumar P, Gaur PM, Sharma HC,Pande S, Sharma M, Krishnamurthy L, Zaman MA et al. (2011) Adaptation of grain legumes to climate change: a review. Agron Sustainable Dev 32: 31-44.
8. Shankar M, Sharma HC, Sharma SP, Ramesh Babu T and Sridevi D (2013) Evaluation of no-choice cage, detached leaf and diet incorporation assays to screen chickpeas for resistance to the

beet armyworm *Spodoptera exigua* (Lepidoptera: Noctuidae). International J Tropical Insect Sci doi:10.1017/S1742758413000374.

9. Shankar M, Sharma, HC, Ramesh Babu T and Sridevi D (2013)Evaluation of chickpea genotypes for resistance to beet armyworm, *Spodoptera exigua* under field conditions. Indian J Plant Protection 41: 275-281.
10. Sharma HC (2014) Climate change effects on activity and abundance of insects: Implications for crop protection and food security. J Crop Improv 28: 229-259.
11. War AR, Paulraj MG, Hussain Barkat, Buhroo AA, Ignacimuthu S and Sharma HC. 2013. Effect of plant secondary metabolites on legume pod borer *Helicoverpaarmigera.* J Pest Science86: 399–408.

Seminar/Conference papers

1. Sharma M, Nagavardhini A, Pande S 2013. Race scenario of *Fusarium oxysporum* sp. *Ciceris* wilt pathogen of chickpea (*Cicer arietinum* L. [Abstract] Page 58 *in* 12th European Fusarium Seminar, 12-16 May 2013, INRA UR1264 MycSA, 71 avenue E. Bourlaux, CS20032, 33882 Villenaved'Ornon, France.
2. Sharma M. and Pande S. 2013.Impact of climate change variables on diseases of chickpea and pigeonpea in semi-arid tropics (Abstract O09.005) Page 160 in Acta Phytopatholagica Sinica. 10th International Congress of Plant Pathology (ICPP 2013), 25-30 August, Beijing China.
3. Ghosh R., Sharma M. and Pande S. 2013. Molecular and morphological diversity in *Rhizoctonia bataticola* isolates causing dry root rot of chickpea (Cicer arietinum L.) in India. (Abstract P22.043) Page 297 in Acta Phytopatholagica Sinica. 10th International Congress of Plant Pathology (ICPP 2013), 25-30 August, Beijing China.
4. Sharma M., Kiran Babu T., Gaur P.M., Ghosh R., Rameshwar T. and Pande S.2013. Advances in host plant resistance and identification of *Fusarium oxysporum* f. sp. *ciceris* disease resistance in chickpea genotypes. (Abstract O39.015) Page 514 in Acta Phytopatholagica Sinica. 10th International Congress of Plant Pathology (ICPP 2013), 25-30 August, Beijing China.
5. Senthilraja G, Cheruku JR, Pande S, and Sharma M. 2013. Temperature mediate interactions between the aggressiveness of *Phytophthora drechsleri*f sp. *cajani* and activity of defense enzymes in pigeonpea. Page 15 in International conference on "Green India: Strategic knowledge for combating climate change: Prospects & Challenges (GISKCCC- 2013)", Organized by Department of Ecology and Environmental Sciences, School of Life Sciences, Pondicherry University, Puducherry 605014, India from 5-7 December, 2013.
6. Pande S 2012. Climate change, plant diseases and their management: an overview. *In* Souvenir and Abstracts of National Symposium on " Emerging issues in plant health management" and Annual Meeting of IPS (NZ) September 28-29, 2012, Department of Pathology, Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan- 173 230 (HP), India.
7. Sharma M. 2012. Climate change emerging plant diseases and their management: Recent developments. Pages 43-45 in "Global meet of Biologists and Satellite conference on Vector control and management: Present status and future strategies - Souvenir & Abstracts, 26-28 December 2012, Organised by Department of Zoology Osmania University, Hyderabad, India.

8. Dhillon, M.K. and Sharma, H.C. 2012. Effect of climate change on bioefficacy of IPM technologies. In: *Abstract no. S901M06, Session: 9: Conservation, Biodiversity and Climate Change, of the 24th International Congress of Entomology: New Era in Entomology* held on 19-25 August, 2012 at the EXCO, Daegu, Korea.
9. Pavani T, Ramesh Babu T and Sharma HC. 2013. Variation in incidence of pod borers, *Helicoverpa armigera* and *Spodoptera exigua* in chickpea genotypes across four sowings. In: *International Conference on Biosciences with Special Reference to Environmental Issues (ICBEI-2013)*, 19-21 Dec 2013. Department of Zoology, Shivaji University, Kolhapur, Maharashtra, India.
10. Sharma, H.C. 2012. Biological consequences of climate change: Implications for arthropod diversity, pest management, and food security. In: *International Conference on Biodiversity & Sustainable Development*, 14-15 Sept 2012.OMICS Group Conferences, Hyderabad, Andhra Pradesh, India.
11. Sharma, H.C. 2012. Effect of global warming on insect – host plant – environment interactions. In: *24th International Congress of Entomology*, 19-24 Aug 2012, Daegu, South Korea.
12. Sharma, H.C. 2012. Biological consequences of climate change: Arthropod diversity, pest management, and food security. In: *International Union of Biological Sciences (IUBS), 31st General Assembly*, 5–9 July 2012, Shanghai, China.
13. Sharma, H.C. Pande, S., Sharma, M., Sudini, H.K., Sharma, R. and RangaRao, G.V. 2012. Risk assessment and modeling of biotic stresses in ICRISAT mandate crops. In: Management of critical pests and diseases of RTBs through enhanced risk assessment and surveillance and "Modeling Impacts of CC on pests and diseases, 9 – 17 Dec 2012, International Potato Research Center, Lima, Peru.
14. Sharma HC and War AR. 2013. Constitutive and induced resistance to *Helicoverpa armigera* in grain legumes. In: *61st Annual Meeting, Entomological Society of America*, 10-13 Nov 2013, Austin, Texas, USA.
15. Sharma HC and War AR. 2013. Biological consequences of climate change on arthropods. *International Conference "Green India: Strategic knowledge for combating climate change: Prospects and challenges", GISKCCC2013,* 5-7 Dec 2013, Pondicherry University, Pondicherry, India.

Book chapters

1. Sharma, H.C. 2013. Biological consequences of climate change on arthropod biodiversity and pest Management. In: *New Horizons in Insect Sciences* (Chakravarthy, A.K., Ashok Kumar, C.T., Verghese, A. and Thyagraj, N.E. eds.). *International Conference on Insect Science,* 14-17 Feb 2013, Universiy of Agricultural Sciences, Bangaluru, Karnataka, India.pp. x – xii.
2. Sharma, H.C. and Prabhkar, C.S. 2013.Impact of Climate Change on Pest Management and Food Security. In: *Integrated Pest Management – An Ecological Perspective* (Abrol, D. P., ed.) Elsevier Press (in press).
3. Sharma, H.C. 2013. Climate change effects on activity and abundance of insects: Implications for Crop Protection and Food Security. In: *Combating Climate Change: An Agricultural Perspective* (Kang, M.S. and Banga, S.S, eds.). Taylor and Francis, Boca Raton, Florida, USA. pp. 213-236.
4. Sharmah, B.K., Acherjee, S. and Sharma, H.C. 2012. Chickpea: Crop Improvement under changing

environment conditions. In: *Improving Crop Productivity in Sustainable Agriculture* (Tuteja, N., Gill, S.S. and Tuteja, R. eds.). John Wiley Science Pub.pp. 360-380.

10.3 IARI, Delhi

Papers in the journals

- Chandrakala, J.U., Chaturvedi, A.K., Ramesh, K.V., Rai, P., Khetarpal, S. and Pal, M. (2013). Acclimation response of signaling molecules for high temperature stress on photosynthetic characteristics in rice genotypes. *Ind. J. Plant Physiol.* DOI 10.1007/s40502-013-0021-3.
- Das TK, Bhattacharyya R, Sharma AR, Das S, Saad AA and Pathak H (2013) Indian Impacts of conservation agriculture on total soil organic carbon retention potential under an irrigated agro-ecosystem of the western Indo-Gangetic Plains. Euro J Agron 51:34-42.
- Das TK, Bhattacharyyaa R, Sudhishri S, Sharma AR, Saharawat YS, Bandyopadhyay KK, Sepat S, Bana RS, Aggarwal P, Sharma RK, Bhatia A, Singh G, Datta SP, Kar A, Singh B, Singh P, Pathak H, Vyas AK and Jat ML (2014) Conservation agriculture in an irrigated cotton–wheat system of the western Indo-Gangetic Plains: Crop and water productivity and economic profitability. Field Crops Res 158:24–33.
- Dhakar R, V.K. Sehgal, S. Nagar, V.U.M. Rao, B. BapujiRao, P. Vijay Kumar, A.V.M. SubbaRao, R. Dupal (2013). Impact of drought on sptaio-temporal pattern of phenology in Rajasthan. Journal of Agrometeorology 15: 58 – 63.
- Dhakar R, V.K. Sehgal, S. Pradhan (2013). Study on inter-seasonal and intra-seasonal relationships of meteorological and agricultural drought indices in the Rajasthan State of India. Journal of Arid Environments 97, 108-119.
- Goswami S, Kumar RR, Rai RD (2014) Role of heat responsive micro RNAs (miRNAs), transcription factors and heat shock proteins in regulation of starch granule biosynthesis in wheat (Triticumaestivum) under the terminal heat, Aus. J. Crop Sci. 8(5):697-705.
- Jain N, Dubey R, Dubey DS, Singh J, Khanna M, Pathak H and Bhatia A (2013) Mitigation of greenhouse gas emission with system of rice intensification in the Indo-Gangetic Plains. Paddy Water Environ. DOI 10.1007/s10333-013-0390-2.
- Jha S, V. K. Sehgal, R. Raghava, M. Sinha (2013). Trend of standardized precipitation index during Indian summer monsoon season in agroclimatic zones of India. Earth System Dynamics Discussions, 4(1): 429-449.
- Kumar RR and Rai RD (2014) Can wheat beat the heat: understanding the mechanism of thermotolerance in wheat (Triticumaestivum). Cereal Res. Commun. 42 (1): 1-18.
- Kumar RR, Goswami S, Sharma SK, Gadpayle KA, Singh K, Kumar N, Rai GK, Rai RD (2013) Heat stress associated antioxidant isoenzymes in wheat: expression and proteomics. Indian J. Agric. Res. 47(4):280–287.
- Kumar RR, Goswami S, Singh K, Gadpayle KA, Sharma SK, Singh GP, Pathak H, Rai RD (2013) Ascorbic acid at pre-anthesis modulate the thermotolerance level of wheat (Triticumaestivum) pollen under heat stress. J. Plant Biochem. Biotechnol. DOI 10.1007/s13562-013-0214-x.

- Kumar RR, Goswami S, Singh K, Rai GK, Rai RD (2013) Modulation of redox signaling pathways in plant system through induction of free radical /ROS scavenger molecules. Aus. J. Crop Sci. 7(11):1744-1751.
- Kumar RR, Sharma SK, Goswami S, Singh K, Gadpayle KA, Singh GP, Pathak H, Rai RD (2013) Transcript profiling and biochemical characterization of mitochondrial superoxide dismutase (mtSOD) in Wheat (Triticum aestivum) under exogenous stress. Aus. J. Crop Sci. 7(3):414-424.
- Kumar RR, Sharma SK, Goswami S, Singh R, Pathak H, Rai RD (2013) Characterization of differentially expressed stress-associated proteins in starch granule development under heat stress in wheat (*Triticum aestivum* L.). Indian J. Biochem. Biophys. 50:126-138.
- Kumar RR, Singh GP, Goswami S, Pathak H, Rai RD (2014) Proteome analysis of wheat (*Triticum aestivum*) for the identification of differentially expressed heat-responsive proteins, Aus. J. Crop Sci. 8(6):973-986.
- Kumar Sarvendra, Patra, A.K., Singh, Dhyan, Purakayastha, T. J., Rosin, K.G., Kumar, Manoj (2013) Balanced fertilization along with farmyard manures enhances abundance of microbial groups and their resistance and resilience against heat stress. Communications in Soil Science and Plant Analysis 44: 2299-2313. (NAAS IF: 6.42).
- Kumar Sarvendra, Patra, A.K., Singh, Dhyan, Purakayastha, T. J., Rosin, K.G., Kumar, Manoj (2013) Long-term chemical fertilization along with farmyard manure enhances resistance and resilience of soil microbial activity against heat stress. Journal of Agronomy and Crop Science doi:10.1111/jac.12050 (published on line). (NAAS IF: 8.15).
- Naresh Kumar S., P.M. Govindakrishnan, D.N. Swarooparani, Ch. Nitin, J. Surabhi, P.K. Aggarwal 2015. Assessment of impact of climate change on potato and potential adaptation gains in the Indo-Gangetic Plains of India. International Journal of Plant Production 9 (1), 151-170.
- Naresh Kumar S, P. K. Aggarwal, D. N. Swarooparani, Rani Saxena, Nitin Chauhan, Surabhi Jain (2014a). Vulnerability of wheat production to climate change in India. Climate Research. doi: 10.3354/cr01212.
- Naresh Kumar S., Pramod Kumar Aggarwal, Kumar Uttam, Jain Surabhi, D. N. Swaroopa Rani, Nitin Chauhan and Rani Saxena (2014b). Vulnerability of Indian mustard (Brassica juncea (L.) Czernj. Cosson) to climate variability and future adaptation strategies. Mitigation and Adaptation Strategies to Global Change. 10.1007/s11027-014-9606-Z.
- Naresh Kumar, S., P. K. Aggarwal, Rani Saxena, Swaroopa Rani, Surabhi Jain and Nitin Chauhan. 2013. An assessment of regional vulnerability of rice to climate change in India. Clim. Change. DOI 10.1007/s10584-013-0698-3. 118 issue 3-4 June 2013. p. 683 – 699.
- Pal, M., Chaturvedi, A.K., Shah, D., Bahuguna, R.N., Sadhana, Singh, S., Mukhopadhyay, D., Khetarpal, S., Anand, A., Deshmukh, P. S., Bhardwaj, C. and Kumar, J. (2013). Growth dynamics and temperature sensitivity of late planting chickpea under Delhi conditions. *Indian J. Plant Physiol.*, 18(1):79-82. DOI 10.1007/s40502-013-0013-3.
- Pathak H (2013) Climate change and efficient nitrogen management. Geography You 13:33-35.
- Pathak H (2013) Nitrogen and climate change: Interactions, impacts, mitigation and adaptation. J Indian Soc Soil Sci 60:109-119.

- Pathak H, Sankhyan S, Dubey DS, Bhatia A and Jain N (2013) Dry direct-seeding of rice for mitigating greenhouse gas emission: Field experimentation and simulation. Paddy Water Environ. 11:593–601.
- Saha S, V.K. Sehgal, D. Chakraborty, M. Pal (2013). Growth Behavior of kabuli Chickpea under Elevated Atmospheric CO2. Journal of Agricultural Physics 13(1):55-61.
- Sinha P, K Kamble, Vivek Singh, Ritesh, Taru Sharma, U D Singh, Robin Gogoi, R S Bal, Pathak H and V K Sehgal (2013). Yellow rust threatening wheat under extreme cold in north western India: GIS linked risk map for disease monitoring. Indian Farming 63: 24.
- Sujithra, M. and Chander, S. 2013. Simulation of rice brown planthopper, Nilaparvatalugens population and crop-pest interactions to assess climate change impact. Climatic Change 121: 331-347, DOI 10.1007/s 10584-013-0878-1.
- Viani A, Sinha P, Ritesh Singh and Vivek Singh (2013). Simulation of spot blotch in wheat under elevated temperature. Ann. Pl. Protec. Sci. 21: 368-376.

Papers in the proceedings of workshop/conferences

- Verma, P., Kumar, R.R., Goswami, S., Sharma, S.K., Rai, R.D. (2014) Proteomic characterization for identification of heat-responsive proteins in wheat (*Triticum aestivum*). International conference on biodiversity, bioresources and biotechnology, Society for Applied Biotechnology (SAB), Mysore, Karnataka, Pg. 88.
- Reddy, S., Kumar, R.R., Goswami, S.,Sharma, S.K., Rai, R.D. (2014) Exogenous effect of signaling moelcules and heavy metals on the accumulation of free amino acid under heat stress in wheat (*Triticum aestivum* L). National Conference on Science of Omics for Agricultural Productivity: Future prospective, GB Pant University of Agriculture and Technology, Uttrakhand, Pg. 98.
- N. Jain et al., Adaptation and mitigation strategies for compensating yield loss of late-planted rice in the Indo-Gangetic plains, "International Conference on Harnessing of Natural Resources for Sustainable Development: Global Trend", under the sub-theme "Global climate change impact and management", 29-31st Jan 2014, Guwahati, Assam.
- Kumar, R.R., Singh, G.P., Goswami,S., Pathak,H., Rai,R.D. (2014) Gel based and label-free proteomic analysis of heat-responsive proteins in wheat (*Triticumaestivum* L) under heat stress. National Conference on Science of Omics for Agricultural Productivity: Future prospective, GB Pant University of Agriculture and Technology, Uttrakhand, Pg. 39.
- Kumar, R.R., Sharma, S.K., Goswami,S., Rai,R.D. (2013) Differential expression of SAPs in starch granule biosynthesis in wheat (*Triticumaestivum*), International conference on role of plant biochemistry and biotechnology in food and nutritional security (ICBBFN2013), Department of Biochemistry and Sri Venkateswara University, Triupati, Pg. 80-81.
- Kumar, R.R., Pathak, H., Sharma, S.K.,Singh, G.P., Rai, G.K., Goswami,S., Rai,R.D. (2014) Omics approaches for deciphering the mechanism of thermotolerance and development of climate smart wheat (*Triticumaestivum* L). XVI Indian Agricultural Scientist and Farmers Congress on Nano-biotechnological approaches for sustainable agriculture and rural development, Bioved Research Institute of Agriculture and Technology and Integral University, Lucknow, Pg. 12.

- Kumar, R.R., Sharma, S.K., Goswami S., Choudhary, M., Singh, K., Gadpayle, K.A., Singh, G.P., Pathak, H., Rai, R.D. (2013) Can wheat beat the heat: Effect of heat stress on expression of stress associated proteins and perturbation in starch granule structure, International conference on "Bio-resource and stress management" Kolkata, p. 69.
- Kumar, R.R., Sharma, S.K., Goswami S., Choudhary, M., Singh, K., Gadpayle, K.A., Singh, G.P., Pathak, H., Rai, R.D. (2013) Can wheat beat the heat: Effect of heat stress on expression of stress associated proteins and perturbation in starch granule structure, International conference on "Bio-resource and stress management" Kolkata, Pg. 69.
- Kumar, R.R., Sharma, S.K., Goswami S., Dhawan, G., Singh, K., Kumar, N., Singh, G.P., Pathak, H., Rai, R.D. (2013) Differential expression of stress associated genes in wheat (*Triticum aestivum*) pollen under ascorbic acid and heat stress and its effect on thermotolerance capacity, First International and Third National Conference on Biotechnology, Bioinformatics and Bioengineering' organised by *Society for Applied Biotechnology*, 28-29 June 2013, Tirupati, Andhra Pradesh, Pg. 38.
- Gupta, R., Kumar, R.R., Sharma, S.K., Kumar, N., Goswami, S., Rai, R.D. (2014) Early sowing modulates the peroxidase activity and attenuates the H_2O_2 induced lipid peroxidation in wheat (*Triticum aestivum*). International conference on biodiversity, bioresources and biotechnology, Society for Applied Biotechnology (SAB), Mysore, Karnataka, Pg. 88.

11. Training/Awareness Programmes Conducted

11.1 TNAU, Coimbatore

1. Focus group meeting and discussion with farmers organized as a part of situation analysis.
2. Two scholars have been trained on climate model downscaling to generate location specific future climate projections.
3. Three scholars have been trained on handling SWAT model in analysing the hydrology and crops productivity at river basin scale.
4. Three scholars have been trained on dynamic crop simulation models such as DSSAT and APSIM in assessing the impact of climate on crops growth and productivity.
5. One student was trained on developing nano fertilizers and assessing the nutrient release pattern.

11.2 ICRISAT, Hyderabad

1. Conducted training on diagnosis and high throughput phenotyping of chickpea and pigeonpea diseases under changed climate scenario during December 2012.
2. Training in impact of climate change on diseases and insect pests during various training course on crop improvement.
3. Organized a symposium on, "Conservation, Biodiversity and Climate Change" in 24th International Congress of Entomology, 19-25 August, 2012, Daegu, South Korea.
4. Exposure visits of students, scientists/researchers from various universities and institutions and visit of from national /international organizations.
5. Seven Ph.D. students and post docs trained on various aspects of climate change and plant diseases in chickpea and pigeonpea.
6. Seven Ph.D. students and post docs trained on climate change and insect-pests in chickpea and pigeonpea.

11.3 IARI, New Delhi

1. Five group meeting and discussion with scientists, technical staff and farmers organized for developing and prioritizing adaptation options.
2. Three senior research fellows have been trained on climate change adaptation and mitigation.
3. Two technical staff have been trained on climate change adaptation and mitigation.
4. Exposure visits of students, scientists, researchers from various universities and institutions were organized.