Climate Change and Indian Agriculture: Impact, Adaptation and Vulnerability

Salient Achievements from ICAR Network Project

Compiled and Edited by

S. Naresh Kumar
Anil Kumar Singh
P.K. Aggarwal
V.U.M. Rao
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Division of Environmental Sciences

Indian Agricultural Research Institute

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Coordinating centre
Indian Agricultural Research Institute, New Delhi

Collaborating centres	Period
• Indian Agricultural Research Institute, New Delhi	2004-2012
• Central Research Institute for Dryland Agriculture, Hyderabad	2004-2012
• Indian Institute of Horticultural Research Institute, Bangalore	2004-2012
• Central Plantation Crops Research Institute, Kasaragod	2004-2012
• Central Soil and Water Conservation Research and Training Institute, Dehradun	2004-2012
• ICAR Research Complex for Eastern Region, Patna	2004-2012
• National Dairy Research Institute, Karnal	2004-2012
• Central Marine Fisheries Research Institute, Cochin	2004-2012
• Central Inland Fisheries Research Institute, Barrackpore	2004-2012
• Tamil Nadu Agricultural University, Coimbatore	2004-2012
• CSK Himachal Pradesh Agricultural University, Palampur	2004-2012
• Bidhan Chandra Krishi Vidyapeeth, Kalyani, West Bengal	2009-2012
• National Bureau of Soil Survey and Land Use Planning, Nagpur	2009-2012
• Central Potato Research Institute, Shimla, Himachal Pradesh	2009-2012
• NRC on Agroforestry, Jhansi, Uttar Pradesh	2009-2012
• Central Soil Salinity Research Institute, Lucknow	2009-2012
• ICAR Complex for NEH Region, Barapani, Meghalaya	2009-2012
• Project Directorate on Poultry, Hyderabad	2009-2012
• Toklai Experimental Station, Jorhat, Assam	2009-2012
• Anand Agricultural University, Anand, Gujarat	2009-2012
• Project Directorate on Soybean, Indore	2009-2012
• Indian Institute of Sugarcane Research, Lucknow	2009-2012
• Punjab Agricultural University, Ludhiana	2009-2012
• Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur	2004-2007
• University of Horticulture and Forestry, Solan	2004-2007
• Indian Institute of Soil Science, Bhopal	2004-2007
• Narendra Dev University of Agriculture and Technology, Faizabad	2004-2007

Contents

Background

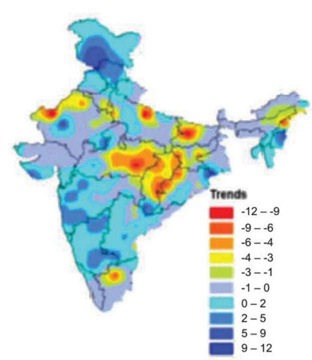
Climate change is increasingly seen as the major threat to the food security and sustainability of agriculture in India. Keeping in view of the importance of this problem, Indian Council of Agricultural Research initiated a National Network project on '**Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change'.** The nation-wide network project, first of its kind in ICAR, was started in 2004 during the X Plan with 15 Institutes which was increased to 23 in XI Plan (2007-2012). These institutes/universities covered all major sectors of agriculture viz., crops, horticulture, plantations, live-stock, inland and marine fisheries, poultry and natural resources like water and soil.

The project was initiated with the objectives to:

1. Quantify the sensitivities of current food production systems to different scenarios of climatic change by integrating the response of different sectors
2. Quantify the least-risk or 'no regrets' options in view of uncertainty of global environmental change which would also be useful in sustainable agricultural development
3. Determine the available management and genetic adaptation strategies for climatic change and climatic variability
4. Determine the mitigation options for reducing global climatic changes in agro-ecosystems, and
5. Provide policy support for the international negotiations on global climatic changes.

The salient achievements under this project during 2004-12 period are summarized in this publication.

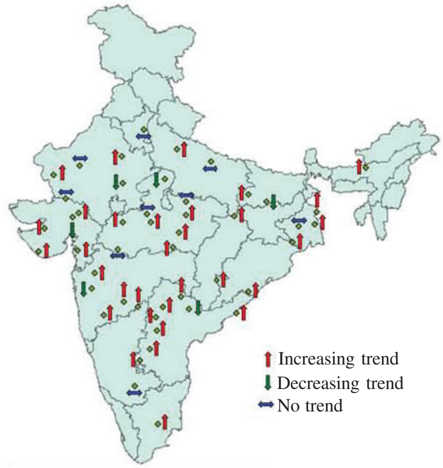
Past trends in climate



Long-term annual rainfall pattern (Mann Kendall test)

1. Analysis of the long-term series of annual rainfall data from 1140 rain gauge stations across the country indicated significant negative trends in the eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, Uttar Pradesh, parts of northwest and northeast India and in a small part of Tamil Nadu. However, significant increasing rainfall trends have been noticed in Jammu and Kashmir and in some parts of southern peninsula
2. Analysis also indicated increasing trends in annual rainfall, and minimum temperature in parts of Bihar, West Bengal and Gujarat. In Punjab, the annual and seasonal minimum

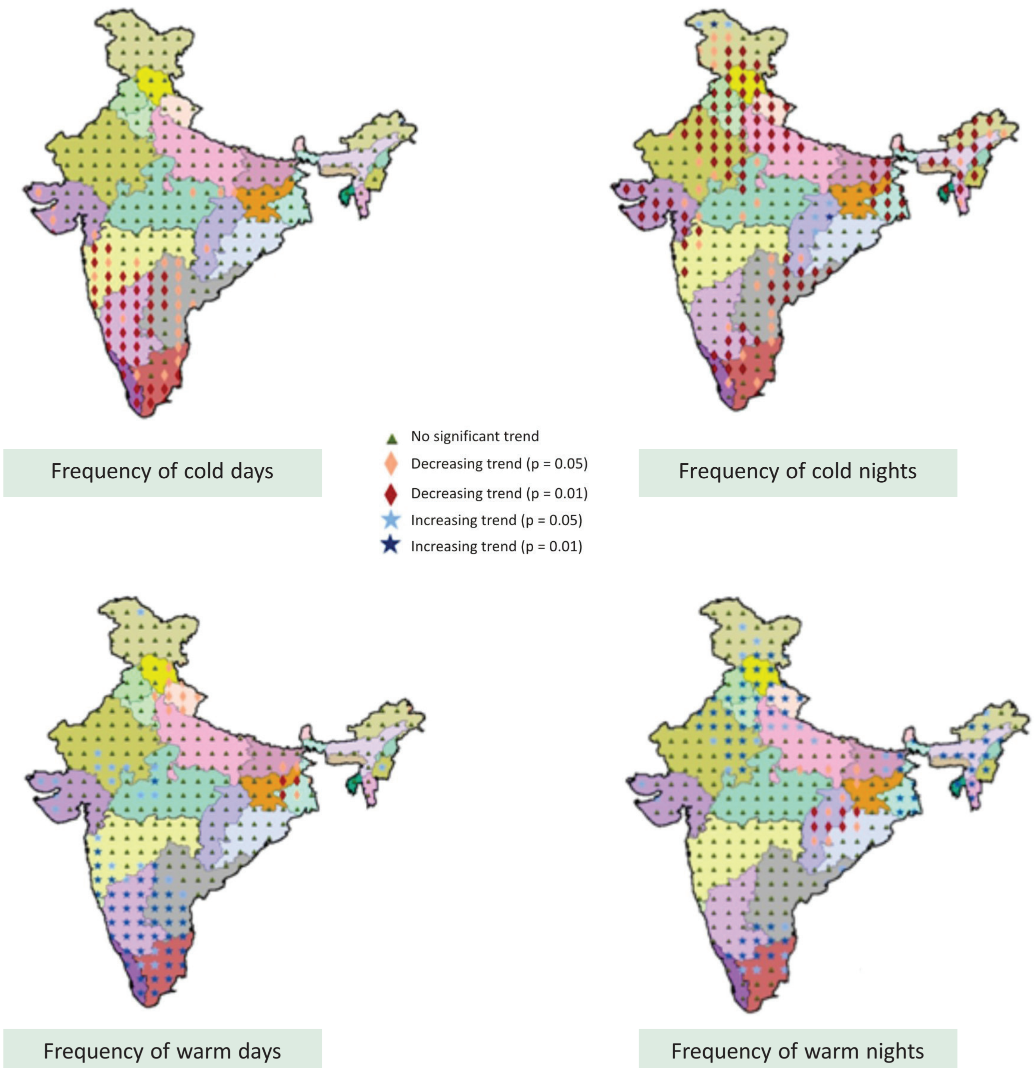
temperature has increased over the past three decades in the range of 0.02-0.07 °C/year. Analysis on mean annual temperature at 47 locations spread across the country indicated an increasing trend in the central and southern parts and north eastern region. While decreasing trends were observed in some parts of Gujarat, Konkan region, north western parts of Madhya Pradesh and Eastern Rajasthan. The analysis of past 108 years rainfall data at Ludhiana revealed that the annual, monsoon and summer season rainfall has increased. In Andhra Pradesh, the percentage of occurrence of droughts was more during 1971-1980 and 1991-2000 decades when compared to 1981-1990 decade in all agro-climatic zones except in southern and in scarce rainfall zones.



Long-term mean annual temperature trends

Trends in extreme weather events

1. Analysis of occurrence of extreme weather events during past six decades indicated an increasing trend in maximum one-day precipitation in the west coast of Maharashtra, south Madhya Pradesh, east Bihar, Assam, north and west Karnataka, eastern Uttar Pradesh, western Jharkhand and Ganga Nagar area of Rajasthan. On the other hand, a declining trend was observed in parts of southern Karnataka, western Maharashtra, northern Chhattisgarh, northern Madhya Pradesh, and western Uttar Pradesh.
2. The frequency of occurrence of cold days during the past five decades significantly declined in north western Madhya Pradesh, southern Chhattisgarh, western Gujarat and in parts of peninsular India. Frequency of occurrence of cold nights declined in major parts of north India, south and west Gujarat, west Maharashtra, coastal Andhra Pradesh, southern Karnataka, north western Tamil Nadu and northern Kerala. On the other hand it increased in north Chhattisgarh and northern Jammu and Kashmir states.
3. The frequency of occurrence of warm days significantly increased in parts of southern Rajasthan, western Madhya Pradesh, western Gujarat, northern Jammu and Kashmir and Manipur, while it declined in parts of West Bengal, Jharkhand, southern Bihar, eastern Himachal Pradesh, Uttarakhand, north western Uttar Pradesh and northern Haryana. In peninsular India, frequencies of warm days increased except in north and eastern Andhra Pradesh, southern Tamil Nadu, northern Karnataka and in south and north of Maharashtra.

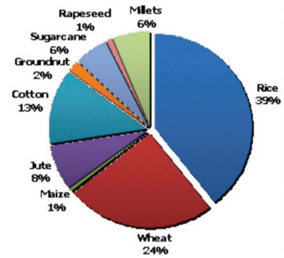


The frequency of occurrence of warm nights significantly increased in many parts of India, while it declined in Chhattisgarh, northern Odisha, southern Uttar Pradesh, western Bihar and Jharkhand.

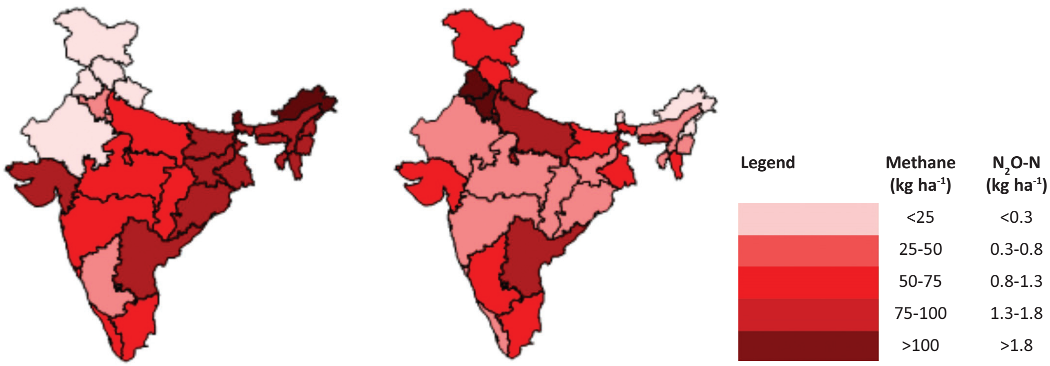
Greenhouse gas emission from Indian agriculture

1. The inventory of greenhouse gas (GHG) emission for the year 2007 indicated that Indian rice fields covering an area of 43.86 million hectares emitted 3.37 million tons of CH_4. Total N_2O emission from agricultural soils of India was 0.22 million tons. Burning of crop residues in fields emitted 0.25 million tons of CH_4 and 0.01 million tons of N_2O.

Greenhouse gas emission from Indian agriculture			
Source	Methane	Nitrous oxide	CO_2 eq.
		Million ton	
Rice cultivation	3.37	-	84.24
Agricultural soil	-	0.22	64.70
Crop residue burning	0.25	0.01	8.21
Total	**3.62**	**0.23**	**157.15**



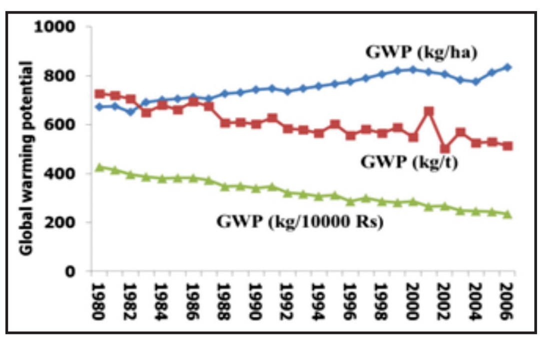
Contribution of various crop residues to GHG emission



Emission of methane and nitrous oxide in different states of India

2. Agricultural soils emitted 16% of the total CO_2 eq. emission from agriculture and 20% of the emissions were from rice cultivation. Emission of GHG from agriculture in different states showed that Punjab, Haryana, Uttar Pradesh and Andhra Pradesh emitted higher amount of N_2O-N because of higher amount of N fertilizer use. States such as West Bengal, Andhra Pradesh, Odisha, Bihar, Jharkhand and north eastern states emitted higher amount of methane per hectare of rice cultivation.

3. Emission of methane from Indian rice fields has remained almost constant since 1980. Emission of nitrous oxide, however, is increasing as a result of higher use of nitrogenous fertilizer over the years. Total GWP (methane x 25 + nitrous oxide x 298) of Indian agriculture per unit area (kg CO_2 eq. ha^{-1}) is, therefore, increasing. However, GWP per unit of produce (kg CO_2 eq. ton^{-1}) is decreasing. Similarly, GHG



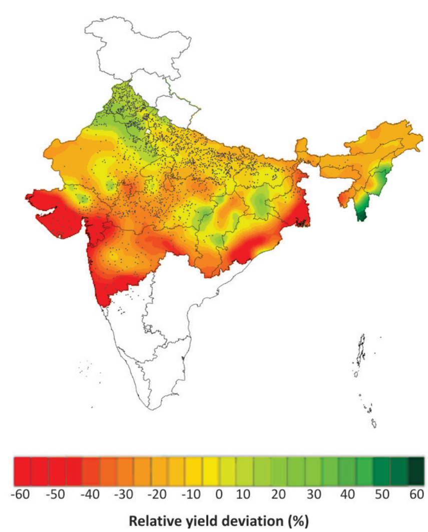
Trend in GHG emission intensity in Indian agriculture intensity per unit agricultural gross domestic product (Ag-GDP) also declined over the years. This decline was due to increase in agricultural production of the country because of adoption of high yielding crop varieties and better crop management practices without increase in area under agriculture.

4. An inventory of enteric methane emission for 2006 was prepared following IPCC guidelines on good practice guidance and uncertainty reduction and using Tier 2 methodology of IPCC. Tier 1 methodology and default factors of IPCC have been used for estimating enteric methane emissions for sheep, goats, equines, pigs and other animals. The emissions for the year 2006 were estimated at 9.39 Tg. $year^{-1}$ from both enteric emissions and manure management. The contribution of indigenous cattle to enteric emission was 38% and that of buffaloes was 43%.

5. It is estimated that annual CO_2 emission of marine fishing boats in India was 3.6 million tons during 2005-2007. The mechanized boats emitted 1.67 tons of CO_2 per ton of fish catch, while motorized boats with outboard engine emitted 0.48 t CO_2 per ton of fish catch. Among the mechanized craft, the trawlers emitted more CO_2 than the gillnetters and dolnetters. Based on the data available on the number and size of fishing boats in India in the past years, it is estimated that CO_2 emission per ton of fish caught has increased by 64% in a period of 25 years.

Regional impacts of climate change on crops and adaptation options

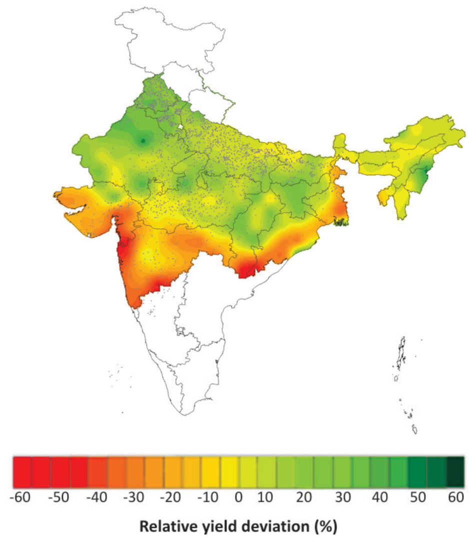
1. Regional impact of climate change, adaptation and vulnerability of irrigated wheat (rabi crop), and irrigated and rainfed rice (in kharif season), maize and sorghum was assessed using the InfoCrop models. The inputs used were IMD 1 x 1° gridded data for baseline period (1969-1990); soil data rescaled to grid values from NBSSLUP and ISRIC soil data base; crop management as per the normal practices followed by the farmers; genetic coefficients of varieties best suitable for different regions and climate change scenarios[1] of MIRO and PRECIS 2020 (2010-2040), 2050 (2041-2070) and 2080 (2081-2100) periods for A1b[1], A2, B1 and B2 emission scenarios. Climate change is projected to reduce the timely sown irrigated wheat production by about 6% in 2020 scenario from existing values. When late and very late sown wheat also is taken into consideration, the impacts are projected to be about 18% in 2020,



Impact of climate change on timely sown irrigated wheat in 2020 scenario

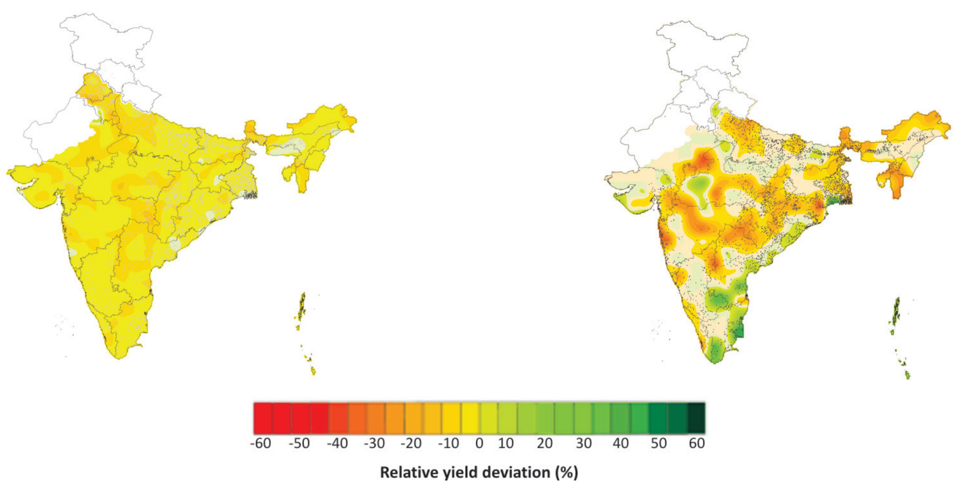
[1] Refer to terminology

23% in 2050 and 25% in 2080 scenarios, if no adaptation measures are followed. However, adaptation to climate change by sowing improved varieties and employing improved input efficiency technologies coupled with application of additional nitrogen can not only offset the negative impacts, but can also improve the net yields by about 10% in 2020. However, in 2050 scenario, such adaptation measures marginally improve yields while in 2080 scenario the wheat yields are projected to be vulnerable by about 6% in spite of above adaptation strategy, thus making it necessary to develop input use efficiency technologies and 'region specific adverse-climate tolerant varieties'.



Net vulnerability of wheat in 2020 scenario

2. On an aggregated scale, in climate scenarios of MIRO and PRECIS, the irrigated rice yields are projected to reduce by ~4% in 2020, 7% in 2050 and by ~10% in 2080 scenarios. On the other hand, rainfed rice yields in India are likely to be reduced by ~6% in 2020 scenario, but in 2050 and 2080 scenarios they are projected to decrease only marginally (<2.5%). Irrigated rice in north-west India, comprising of Haryana and Punjab is projected to lose more (6-8%) than in other parts of the country (<5%) in 2020 scenario. Yield loss will be more in 2050 scenario in north-west India (15-17%) while some parts of

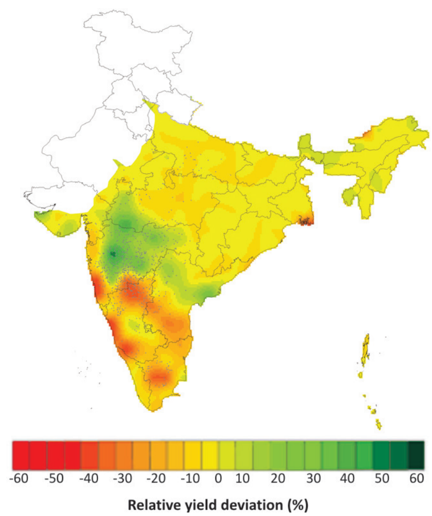


Impact on irrigated rice in 2020 scenario

Impact on rainfed rice in 2020 scenario

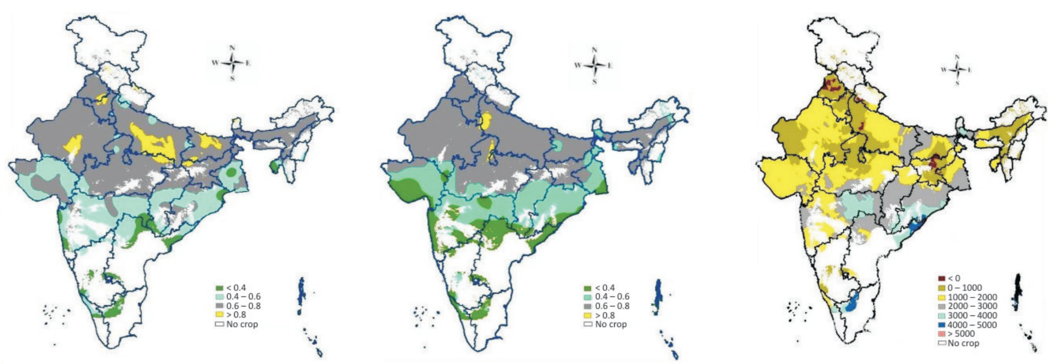
central India (Maharashtra and Madhya Pradesh) also are projected to face >5% of yield loss. Adopting improved varieties with improved input efficiency and providing 25% of additional nitrogen can not only offset the climate change impacts but also can improve the production by 6-17% in irrigated conditions and by about 20 to 35% in rainfed condition in future climate scenarios.

3. Simulation analysis was carried out on the impact of climate change on sorghum and maize crops in India, adaptation strategies and net vulnerability at regional level were also worked out for MIRO and PRECIS climate scenarios. Irrigated kharif maize is projected to reduce yields by upto 18% in 2020 and 2050 scenarios. This adverse effect of climate change is projected to be about 23% in 2080 scenarios. Adaptation strategies such as improved and tolerant variety managed under improved input efficiency with additional nitrogen fertilizer can enhance the irrigated maize net production by about 21% in 2020, 10% in 2050 and 4% in 2080 scenarios. Rainfed sorghum yields, on all India scale, are projected to marginally (2.5%) decline in 2020 scenario while it is projected to decline by about 8% in 2050 scenario. Adaptation to climate change can not only offset the negative impacts but also can improve the yields by about 8% in 2020 scenario.



Impact on rainfed sorghum in 2020 scenario

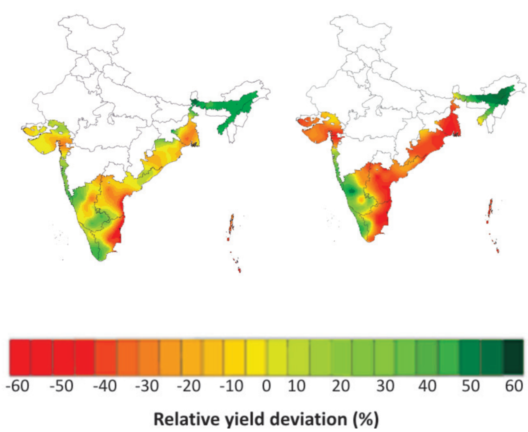
4. Global climate change may increase production of potato in Punjab, Haryana and western and central UP by 3.46 to 7.11% in A1b 2030 scenario, but in rest of India,



The harvest index under baseline (left) and climate change (middle) scenario of potato in India and change in stress degree hours (right) for potato cultivation in climate change scenario particularly West Bengal and southern plateau region, potato production may decline by 4 - 16%. It is primarily the mean minimum temperature during tuber growing period which affects potato yield. The increase in temperature due to climate change may decrease harvest index (HI) in large parts of Maharashtra, parts of Karnataka and Andhra Pradesh. Even though, in the traditional potato growing belt in the Indo-Gangetic plains, the HI may remain more or less the same but pockets of high HI likely to diminish. Analysis on the stress degree hours in winter potato growing regions showed that under the baseline scenario, most of the Indo - Gangetic plains region experienced 1000 to 5000 degree hours of stress due to a combination of both maximum and minimum temperatures. However, under climate change scenario (A1F1) the temperature stress increased further and the area with severe stress (9000 to 13000 degree hours) is projected to increase significantly in large parts of Maharashtra, Jharkand, Odisha and Gujarat. Similarly, pockets with extreme stress (>13000 degree hours) are projected to increase.

5. The simulation results indicated that on an average, future climate would have a positive impact on productivity of rainfed soybean in the country. Increase in soybean yield in the range of 8-13% under different future climate scenarios (2030 and 2080) is projected. In case of groundnut, except in the climate scenario of A1B 2080, which showed a decline of 5% in yield, rest of the scenarios showed 4-7% increase in rainfed yields as compared to the baseline. The maximum positive impact of future climate was observed on chickpea, which showed an average increase in productivity ranging from 23 to 54%. However, a large spatial variability for magnitude of change in the productivity is projected. The simulated rainfed yields of soybean and groundnut showed a strong positive association with crop season rainfall while that of chickpea yields were significantly associated with crop season temperature.

6. Simulation studies using InfoCrop-Coconut model indicated positive effect of climate change on coconut yields in west coast and parts of Tamil Nadu and Karnataka and negative effects on nut yield in east coast of India in HadCM3 A2a, B2a and A1F 2020, 2050 and 2080 scenarios. However, in the event of reduced availability of irrigation, the beneficial impacts will be less or negative impacts will be more. On all India basis, results indicate that climate



Impact of climate change on coconut yield in 2020 (left) and 2080 (right) scenario change positively impacts coconut production in the range of 4.3% in A1B 2030, 1.9 in A1B 2080, 6.8% in A2 2080 and 5.7% in B2 2080 scenarios of PRECIS from existing production levels. The magnitude of impacts (positive or negative) is higher in analysis based on GCM scenarios, than in analysis based on RCM scenarios. Adaptation to climate change can increase the yields by 13-19% in different scenarios thereby increasing the overall production by about 20%.

7. Ricardian approach was followed to analyze the impact of climate change using cross section and time series data for the Tamil Nadu state. Paddy is projected to decrease both in terms of area and productivity, resulting in production loss by 9% in 2020 and by about 13% in 2050 from existing levels. Sugarcane area and productivity is projected to decrease by 9.45 and 13.4 % in short-term and by about 13 and 9%, respectively, in the long - term. Area under groundnut is projected to decrease by 5.12 and 3.65% in medium and long - term, respectively, while groundnut yields are projected to decline by a 7.04% in medium term and by 5.36 % in long term.

8. Analysis of recent weather data in Himachal Pradesh indicated that the maximum temperature is showing an increasing trend during November to April. Increase in the temperature limited the fulfillment of chilling requirement for apple production. The chill units hours showed decreasing trends upto 2400 meter above mean sea level (m amsl) (Kullu and Kinnaur districts). On the other hand increasing trends of chill units at 2700 mamsl suggested that area is becoming suitable for apple cultivation in higher altitude. This is partially attributed for shift of apple belt upwards from 1250 m amsl to 2500 m amsl and increasing area of apple in higher elevations. The new areas of apple cultivation have appeared in Lahaul and Spitti and upper reaches of Kinnaur district of Himachal Pradesh. While the apple productivity in lower elevations was impacted by increase in temperature, it also created opportunity for cultivation of other crops. Increase in temperature in higher elevations created opportunity for cultivation of apple and other fruits and vegetable crops.

Apple crop in Himachal Pradesh

9. Increase in temperature did not show any significant impact on the productivity of other temperate fruits like peach, plum and pear. The tea crop in mid-hill regions also showed a decrease in yield with increase in temperature and decreasing trends of rainfall. Crop phenology revealed hastening of crop maturity in mid hill regions due to increase in temperature during crop seasons.

10. The field experiments indicated that the short-duration terminal- or early-heat tolerant wheat varieties can significantly reduce the adverse effects of heat stress on wheat. Crop diversification can not only reduces the climatic risks but also improves the farm income. Rice cultivars such as Swarna-sub are suitable for water logging conditions. In north-eastern region, short duration rice varieties like Vivek Dhan 82 was found suitable for late transplanting up to mid-August. In-*situ* soil moisture conservation, zero tillage with mulching, crop residue management reduces the risk of crop failure especially during dry season. Field experiments aimed at identifying genetic resources for tolerance to abiotic stress in chickpea led to identification of one line EC 538828 for possessing high yield potential (3000 kg/ha) and tolerance to multiple abiotic stresses such drought, high temperature and low solar radiation. In onion, planting in raised beds can reduce the damage due to heavy rainfall events. In plantation crops such as coconut, soil moisture conservation methods such as mulching in palm basins, drip irrigation, coir pith burial in basin/ trenches are found not only to improve the water use efficiency but also to protect the palms from droughts/ prolonged dry spells.

Response of crops to elevated CO_2 and temperature

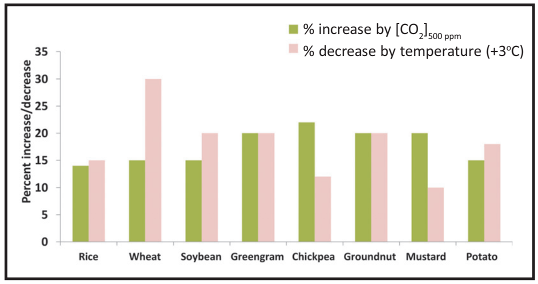
Growth and yield

1. Experiments conducted under controlled environment conditions (FACE, TGT, OTC and portable chambers) to assess the effect of elevated temperature and CO_2 showed that a rise in atmospheric temperature reduced the biomass and yield of wheat, rice, green gram, pigeonpea, soybean, chickpea and potato. Among the crops rice, pigeonpea and chickpea showed greater thermal stability, while wheat showed higher degree of sensitivity to high temperature as compared to greengram, soybean and oilseeds (mustard, groundnut). Rice and chickpea showed greater thermal sensitivity during reproductive growth phase, while pigeonpea and green gram showed greater thermal sensitivity during ripening growth phase. High temperature around flowering period increased pollen sterility in rice and

Free air CO_2 enrichment (FACE) ring

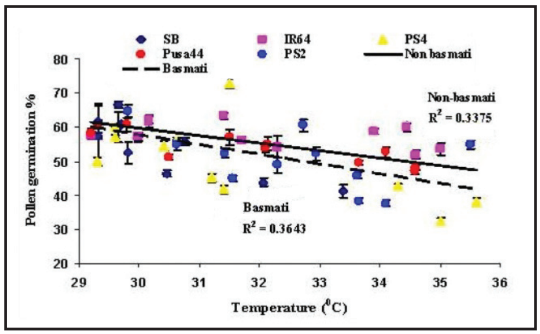
Temperture gradient tunnel (TGT)

reduced pollen germination on stigma. Aromatic rice was more sensitive than non-aromatic rice. In chickpea, exposure to high temperature for a fortnight at flowering period reduced the sterility of pods, and had a beneficial effect on growth and yield. Under controlled environmental conditions, rice varieties Bhalum1 and IURON 514 performed better at elevated temperature (+1.5 °C) condition. During winter season, cole crops like cabbage and cauliflower performed better at elevated temperature (+1.5 °C) condition as compared to that in ambient conditions of Meghalaya.

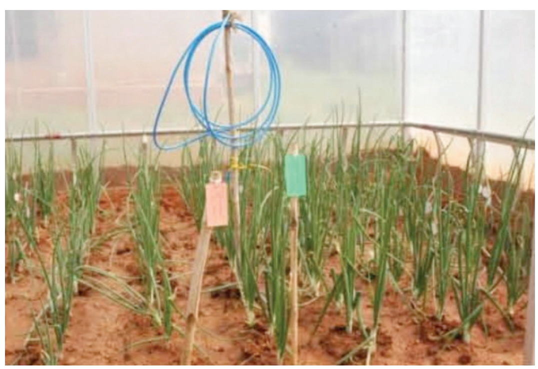


Response of crops to elevated $[CO_2]$ and temperature

2. Elevated $[CO_2]_{550ppm}$ increased the yield of greengram, soybean, chickpea and potato owing to increase in biomass and seed/ tuber number and their size. Groundnut crop showed a positive response to elevated $[CO_2]$ levels for growth and yield and the response was significantly evident at 700ppm. In groundnut moisture stress at initial stages improved the total biomass and pod yield and the response was more at higher levels of $[CO_2]$. Two generations of castor crop showed a significant response under elevated $[CO_2]_{550\ \&\ 700\ ppm}$ in terms of growth, biomass and yield. Adaptation experiments indicated that application of additional fertilizer amount is required to reap the benefits of elevated $[CO_2]$. The average seed yield of eighteen genotypes of black gram improved by 13.6%, 12.5% and 10.5% at $[CO_2]_{550ppm}$ and 24.8%, 13.4% and 32.8% at $[CO_2]_{700ppm}$ during winter, rainy and summer seasons, respectively, over ambient control. Tomato and onion crops showed a yield increase of 25% at elevated $[CO_2]_{550ppm}$. Increased $[CO_2]$ lead to higher biomass and water use



Impact of temperature on rice pollen germination



Onion crop in open top chamber (OTC)

efficiency in plantation crops such as coconut, arecanut and cocoa. Coconut seedlings responded to elevated $[CO_2]_{550 \& 700 ppm}$ also through anatomical modifications in terms of thicker leaves and thick cuticle (~47 and 26%), respectively in 550 and 700µmol mol^{-1}), reduced stomatal density. However, slight reduction in polyphenols may predispose coconut and cocoa plants for pest and disease incidence in elevated CO_2 conditions.

3. In rice cultivars, activity of antioxidant enzymes (Asc.POX, POX, CAT and SOD) increased under high temperature condition even as relative water content was stable. Coconut seedlings grown under elevated $[CO_2]_{550 \& 700}$ conditions had higher concentrations of total soluble sugars, reducing sugars, free amino acids, starch, epicuticular wax and proline in leaf, while the concentration of total phenols, root / shoot CN ratio was less. On the other hand, elevated temperature (+2 °C above ambient) significantly increased concentration of leaf total free amino acids, epicuticular wax, proline, and root/ shoot CN ratio, but decreased the concentrations of soluble sugars, total phenols, reducing sugar and starch. The specific activities of enzymes viz., superoxide dismutase, peroxidase and catalase increased in elevated temperature and $[CO_2]$ treatments as compared to the chamber control. On the other hand polyphenol oxidase specific activity decreased in elevated temperature and $[CO_2]$ treatments. The heat stable protein fraction also increased in elevated temperature conditions and two extra proteins (LMW HSPF ~16 and ~17 KDa) also appeared.
4. The effect of temperature on wheat yield under sodic conditions for past eight years indicated that a rise in temperature by 1 °C in the month of March could reduce the wheat yield to about 8% under sodic soil conditions. The productivity of late sown wheat is affected by the terminal heat stress during March coinciding with the milking stage. Excess sodium accumulation in root zone also aggravated the problem related to Na:K ratio in plant and osmotic potential in soil. It was found that the application of 30% crop residue, additional dose of 40kg K/ha and frequent and light irrigation after booting stage, alone or in combination can minimize the terminal heat effect and adverse effect of Na+ on wheat in sodic soils.
5. The climatic stress in terms of extreme weather events such as heavy rainfall causes flooding damaging the crops, particularly horticultural crops. Flooding for just 24 h had greater impact on tomato and flowering stage was found to be critical. In onion bulb initiation stage is sensitive to flooding, resulting in 27.2 and 48.3% reduction in bulb size and yield, respectively. On the other hand, a four-week water stress on onion bulb yield was lower in Arka Kalyan compared to Agrifound Dark Red.

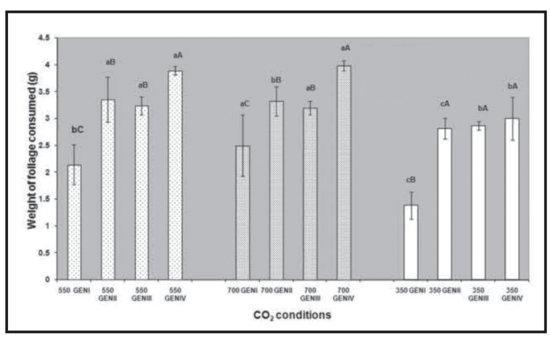
Quality of produce

1. In order to quantify the impact of climate change on quality, analysis was carried out on the economic produce of various crops. Results indicated that protein content of

wheat, greengram and chickpea grain increased marginally with rise in temperature, whereas it decreased marginally with rise in [CO_2] level. Starch content however, showed reverse trend under elevated temperature and CO_2 in wheat grain. Elevated [CO_2] caused a reduction in protein content in rice and a slight reduction of aroma in basmati rice. High temperature reduced test weight and grain elongation, and caused a slight reduction of aroma in basmati rice. The gelatinization temperature increased resulting in firmer cooked rice under high [CO_2]. Oil content of sunflower seed increased markedly under elevated [CO_2] condition. In tomato, even though lycopene and carotenoid content did not differ, antioxidants were higher at elevated [CO_2]$_{550\ ppm}$. In cole crops such as cabbage, the ascorbic acid content was lower under elevated temperature (+1.5 °C) condition. Increase of storage temperature from 22 to 45 °C affected keeping quality of coconut copra and oil; reduced oil percentage while it increased starch, carbohydrates and reducing sugars in copra. High temperature also reduced the shelf life of coconut oil as indicated by increase in free fatty acids, acid value and peroxide value. Increase in storage temperature beyond 28 °C reduced the myristic acid content in arecanuts, thus causing reduction in quality. Proper storage facilities are required to offset the likely rise in temperature in stores under climate change scenarios, in order to avoid the post-harvest quality reduction.

Crop-pest interaction in elevated CO_2 and temperature

1. An increase of 0.5 °C in average temperature in 2006 in Delhi caused a slight decrease in brown plant-hopper population while 1-3 °C rise resulted in significant decline. Temperatures of 30 °C inhibited the growth of ancestral range of *Pseudomonas fluorescence*, whereas evolved lines could tolerate the higher temperatures of 40 °C. Impacts of elevated [CO_2] and temperature on morphology of *Trichoderma viride* and major soil borne pathogens (*Macrophomina phaseolina, Fusarium oxysporum, F. ricini, Rhizoctonia solani*, and *Sclerotium rolfsii*); *Trichoderma viride* (for antagonistic activity); *Pseudomonas* spp. (for PGPR traits) were also assessed. Pest population dynamics models are also developed.
2. The host mediated impact of elevated [CO_2] the crop-pest interaction was observed. Significantly lower concentration of leaf nitrogen, higher C:N ratio and higher concentration of polyphenols in castor and groundnut foliage grown under elevated [CO_2] levels substantially



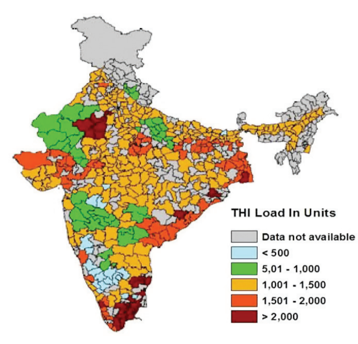
Feeding pattern of pest in four generations under elevated [CO_2] conditions influenced the pests viz., *A. janata* and *S. litura* in terms of prolonged larval duration, higher larval weights and increased consumption of foliage by *A. janata* and *S. litura*as compared to that in ambient [CO_2]. Across four successive generations, approximate digestibility increased by about 9% and relative consumption rate by about 7%. However efficiency of conversion of ingested food decreased by about 13%, as also that of digested food by 19%. The relative growth rate also decreased by 9% in four generations grown under elevated [CO_2] compared to that in ambient conditions. The results indicate that elevated [CO_2] altered the quality of the groundnut foliage resulting in higher consumption by larvae but slowed growth rates leading to longer time for pupation across four generations.

3. Pest prediction equations in relation to temperature were developed for thrips population in horticultural crops. It was observed that thrips on rose required 265 thermal day degrees (TDD) and aphids required 119 TDDs for development.

Crop – soil microbial interaction in elevated CO_2 and temperature

1. In the rhizosphere of groundnut, elevated temperature (+2 to 3 °C) significantly increased the population growth of functional bacteria such as nitrogen-fixing (7%), phosphate-solubilizing (6.6%) and potassium-dissolving (3%) bacteria at 75 days after sowing as compared to the crop grown at ambient temperature, and there seems to be no loss of any PGPR traits amongst the *Pseuodomonas, Azotobacter, Acetobacter and Enterobacter* population.
2. In the rhizospeher of coconut seedlings, soil biochemical parameters were influenced by the rise in temperature (+2 °C) and increase in elevated[CO_2]$_{550\ \&\ 700\ ppm}$. In general, elevated [CO_2] and temperature conditions decreased the concentrations of total soluble sugars and phenols in soil, rate of soil respiration, and the activities of soil enzymes such as urease, phosphatase and dehydrogenase. On the other hand, the activities of invertase and cellulose and concentration of free amino acids increased under elevated temperature (+2 °C).

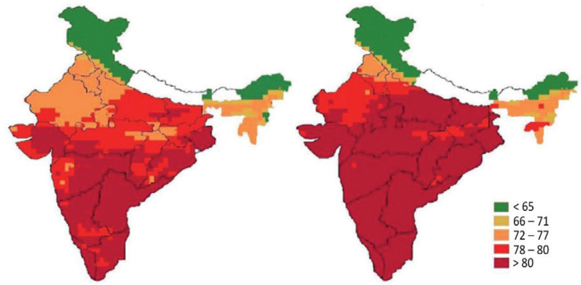
Climate change and dairy sector



Annual THI load on livestock

1. Global warming is likely to lead to a loss of 1.6 million tones in milk production by 2020 and 15 million tons by 2050 in business as usual scenario. Based on temperature-humidity index (THI), the estimated annual loss in milk production at the all-India level by 2020 is valued at about Rs. 2661 crores at current prices. The economic losses may be highest in UP followed by Tamil Nadu, Rajasthan and West Bengal. Stressful THI with 20h or more daily THI-hrs (THI >84) for several weeks affect animal responses. High

producing crossbred cows and buffaloes will be affected more by climate change. Under climate change scenario, increased number of stressful days with a change in temperatures and probable decline in availability of water may further impact animal productivity and health in Punjab, Rajasthan and Tamil Nadu.



THI load in baseline (left) and in 2030 scenario (right) during March

2. The study on expression of heat shock proteins (HSPs) in Sahiwal and Holstein Friesian crossbred (Karan-Fries) heifers indicated that the basal level of HSP72 protein increased due to thermal exposures and was higher in lymphocytes of Sahiwal than that in lymphocytes of Karan-Fries. The threshold temperature for induction of HSP 72 in Tharparkar and Karan Fries cattle was observed to be 42 °C (THI>85) after 4 hours of continuous exposures.

3. A rise of 2-6 °C due to global warming (time slices 2040-2069 and 2070-2099) projected to negatively impact growth, puberty and maturity of crossbreds and buffaloes and time to attain puberty of crossbreds and buffaloes will increase by one to two weeks due to their higher sensitivity to temperature than indigenous cattle.

4. A Livestock Strain Index (LSI) for assessing thermal stress on animals is being suggested to quantify the extent of stress in cattle and buffaloes on a universal scale of 0-10.

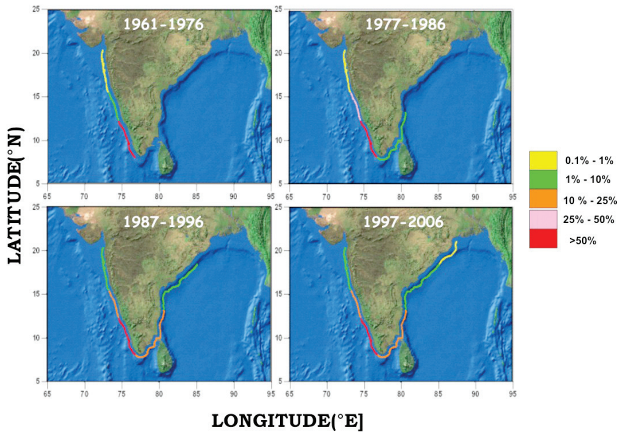
5. Lactating cows and buffaloes have higher body temperature and are unable to maintain thermal balance. Body temperature of buffaloes and cows producing milk is 1.5-2 °C higher than their normal temperature, therefore more efficient cooling devices are required to reduce thermal load of lactating animals as current measures are becoming ineffective. Alleviation of body heat in cattle and buffaloes using blast angular fan and mist system helped in lowering the core body temperature and improved the milk production.

Climate change and fisheries

Marine fisheries

1. A rise in temperature as small as 1°C could have important and rapid effects on the development of fish and their geographical distributions. Oil sardine *Sardinellalongiceps* fishery did not exist before 1976 in the northern latitudes and along the east coast of India as the resource was not available and sea surface temperature (SST) were not congenial. With warming of sea surface, the oil sardine is able to find temperature to

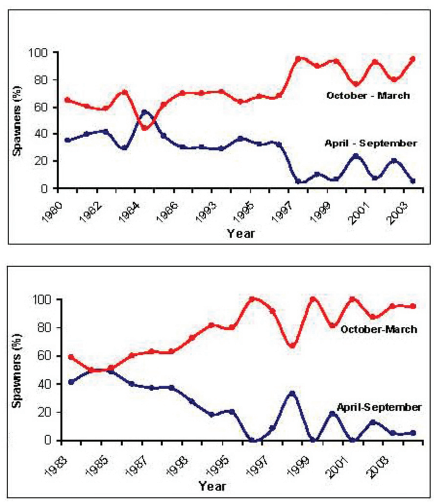
its preference especially in the northern latitudes and eastern longitudes, thereby extending the distributional boundaries and establishing fisheries in larger coastal areas. ECOPATH model with Ecosim simulation developed for northwest coast ecosystem showed that the biomass of oil sardine closely followed the change in fishing effort. The highest increase in biomass (more than 3-times) occurred in the group of small pelagic herbivores consisting of oil sardine. This shows that the biomass of small pelagic herbivores in the ecosystem is likely to increase in future (even under very heavy high fishing pressure), which will be reflected in the catch. Simulations further indicate that most other fisheries groups in the ecosystem may not be impacted immediately due to increase in the biomass of small pelagic herbivores.



Latitudinal shift in abundance of oil sardine along Indian cost

2. The dominant demersal fish, the threadfin breams have responded to increase in SST by shifting the spawning season off Chennai. During past 30 years period, the spawning activity of *Nemipterus japonicus* reduced in summer months and shifted towards cooler months. A similar trend was observed in *Nemipterus mesoprion* too.

3. Analysis of historical data showed that the Indian mackerel is able to adapt to rise in sea surface temperature by extending distribution towards northern latitudes, and by descending to depths.



Change in spawning season of *Nemipterus japonicus* (top) and *N. mesoprion* (bottom) off Chennai

4. Laboratory experiments on the effect of seawater temperature on seven marine phytoplankton species showed that the microalgae grew faster at higher temperature (29 °C), but the decay set-in earlier than at lower temperature (24 °C). The dominance ranking of the microalgae differed between the two temperatures. This shows the

temperature-related changes in the abundance and species dominance of phytoplankton, indicating the potential impacts on the base of food web in the marine ecosystems. The coastal upwelling index during southwest monsoon increased by nearly 50% from 1997 to 2007. The high concentration and increasing trend of Chl a during the monsoon can be beneficial to herbivorous small pelagics.

5. Corals in Indian Ocean will be soon exposed to summer temperatures that will exceed the thermal thresholds observed over the last 20 years. Annual bleaching of corals will become almost a certainty from 2050. Given the implication that reefs will not be able to sustain catastrophic events more than 3 times a decade, reef building corals are likely to start disappear as dominant organisms on coral reefs between 2030 and 2040 and the reefs are likely to become remnant between 2050 and 2060 in the Gulf of Mannar.

Inland fisheries

1. In recent years the phenomenon of Indian major carps maturing and spawning as early as March is observed in West Bengal with its breeding season extending from 110-120 days (Pre 1980-85) to 160-170 days (2000-2005). As a result it has been possible to breed them twice in a year at an interval ranging from 30-60 days. A prime factor influencing this trend is elevated temperature, which stimulate the endocrine glands and help in the maturation of the gonads of Indian major carp. Since low oxygen is a problem with enhanced temperature, substitution with low oxygen tolerant species like catfishes in the culture system may be useful.

2. Under controlled laboratory conditions, the fingerlings of inland fish species, *L. rohita* were kept in different temperatures and feeding. The fishes showed progressive increase upto 38% in food conversation, food consumption, specific growth and weight gain in the thermal range between 29 ^{o}C and 34 ^{o}C but the trend reversed with further increase in temperature to 35 ^{o}C.

3. Recent climatic patterns have brought about hydrological changes in the flow pattern of river Ganga. This has been one of the major factor resulting in erratic breeding and decline in fish spawn availability. As a result, the total average fish landing in the Ganga river system declined from 85.21 tons during 1959 to 62.48 tons during 2004. In the middle and lower Ganga, sixty genera of phytoplankton were recorded during 1959 which declined to 44 numbers by 1996. In case of zooplankton during the same period, the number diminished from 38 to 26. A number of fish species, which were predominantly only available in the lower and middle Ganga in 1950s, are now found in the upper cold-water stretch up to Tehri.

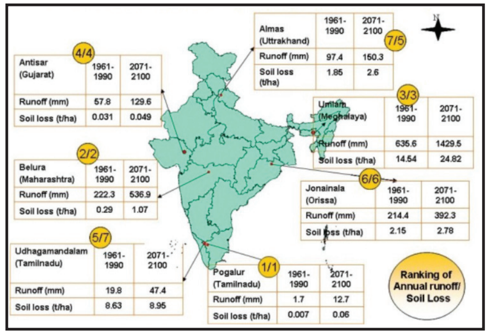
Climate change and poultry sector

1. In poultry sector, mortality due to heat stress occurred at about 34 °C, was significantly high in heavy meat type chickens (8.4%) as compared to light layer type (0.84%) and native type (0.32%) chickens. Increase in temperature from 31.6 °C to 37.9 °C decreased feed consumption by about 36% and egg production up to 7.5% in broiler breeders and up to 6.4% in commercial layers as compared to their standard egg production percentages. The critical body temperature at which the birds succumb to death was 45 °C which was observed at the shed temperature of 42 °C. The respiratory rate increased from 46 min^{-1} at shed temperature of 28 °C to 150 min^{-1} at 42 °C The naked neck birds performed significantly better than the normal birds with respect to thermo-tolerance, growth, feed efficiency and immunity in high temperatures as compared to normal broilers. The sperm viability and fertilizing ability, and live sperm counts were significantly reduced during high ambient temperature. High ambient temperature significantly reduced fertility and hatchability in breeder chicken as well. The immune response to Newcastle disease vaccine and Sheep Red Blood cell antigen was significantly less in high ambient temperature. The epigenetic adaptation to high temperature during late embryonic development increased the post-hatch performance and thermotolerance in broilers.

Climate change and natural resources

1. Simulation results projected an increase in mean annual streamflow in several river basins in PRECIS climate scenarios. In spite of increase in annual streamflow, a decrease in monthly streamflow during summer months (February – June) is projected. In Brahmaniriver basin, the magnitude of change in annual streamflow varied with GCMs and emission scenarios. Ensemble average value indicated 6, 11, and 24% increase in annual streamflow during 2020, 2050 and 2080 respectively under A2 emission scenario; and 6, 14, and 29% increase during 2020, 2050 and 2080, respectively under B2 emission scenario.
2. Hydroloical simulation using the projected changes in rainfall and temperature as per six different GCMs indicated an increase of 8, 15 and 39% in annual streamflow in the upper Bhavani sub-basin during 2020, 2050 and 2080, respectively under A2a emission and 16, 13 and 22% increase in annual streamflow under B2a emission scenario during 2020, 2050 and 2080, respectively. In case of Moyarsub-basin, projected increase is 1, 11.2 and 34.3% in annual streamflow during 2020, 2050 and 2080, respectively under A2a emission and 12.3, 12.2 and 19.4% increase in annual streamflow under B2a emission scenario during 2020, 2050 and 2080, respectively.
3. Annual runoff analysis using SWAT model indicated a decreasing trend of runoff and soil loss with increase in latitude. The runoff at Pogalur, Coimdatore, Tamil Nadu is expected to increase by 6 to 12 times during 2071-2100 than that of 1961-1990. The

runoff at Jonainala, Keonghargarh, Odisha is projected to increase between 83 and 111% and at Belura, Akola, Maharashtra between 142 and 182% in comparison to the runoff of 1961-1990. The runoff at Antisar, Kheda, Gujarat is assessed to increase between 117 and 227% during 2071-2100. The runoff at Almas, Tehri, Uttrakhand; Umiam, Shillong, Meghalaya and Udhagamandalam, Nilgiris, Tamil Nadu is projected to increase by 56 to 132, 96 to 171 and 94 to 309% than the runoff available during 1961-90. Most of the increase in runoff is projected to be during monsoon season. In future, soil conservation efforts would need greater focus in peninsular and central India because of the projected high runoff and soil losses associated with global climate change.



Annual runoff and soil loss during 1961-90 and 2071-2100 from different agro-ecological regions of the country

4. Soil datasets for 117 soil series representing 60 agro-ecological sub-regions of the country are compiled in a user-friendly manner. Datasets on soil series, climate, land use and crop management were documented for use in Rothamsted C, Century C and InfoCrop simulation models. Simulation analysis indicated that an increase of 2.5 ^{o}C caused variable decrease in total organic carbon in different layers of soil. Treating the entire soil pedon as a homogenous unit will over - estimate the effects of global warming in accelerating decomposition of soil carbon.

GHG Mitigation options

Carbon sequestration

1. Agroforestry has maximum carbon sequestration potential in subtropical climate and the least in dry temperate regions. Its carbon sequestration potential decreased with the increase in altitudinal gradient from 468 m amsl – 2100 m amsl. Agri-silvicultureandagri- horti-silviculture are the most suitable agroforestry systems to be used in for carbon sequestration in subtropical climate type. Agri-horticulture has been the most suitable system for carbon sequestration in temperate climate among the four climate types. Carbon sequestration potential of agro-forestry in Bundelkhand region

Agroforestry system

is estimated to be around 22.42 Mg C ha^{-1} and is likely to increase up to 35.78 Mg C ha^{-1} at end of rotation period. The tree biomass, soil carbon and carbon sequestration potential of the region in 2030 is projected to be 67.42, 35.36 and 72.77 million Mg, respectively. Carbon sequestration potential of agroforestry practices middle Gangetic plains (Jaunpur, Pratapgarh, Azamgarh and Basti districts) ranged from 18.5 to 21.80 Mg C ha^{-1}, during 2011 and after 24 years it is projected to increase in the range of 28-38 Mg C ha^{-1}.

Coconut based high density multi-species cropping system

2. Annual carbon sequestration in coconut above ground biomass varied from 15 Mg CO_2 ha^{-1} to 35 Mg CO_2 ha^{-1} depending on cultivar, agro-climatic zone, soil type and management. Annually sequestered carbon stocked in to stem in the range of 0. 3 to 2.3 Mg $CO_2 ha^{-1}$. Standing carbon stocks in 16 year old coconut cultivars in different agro-climatic zones varied from 15 to 60 Mg CO_2 ha^{-1}. The carbon sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils. Simulation analysis indicated that the carbon sequestration in stems of coconut plantations in states like Andhra Pradesh and Tamil Nadu is projected to reduce by about 10 and 31%, respectively in PRECIS A1B 2030 scenario. However, in Karnataka and Kerala climate change is projected to increase the carbon sequestration into stem by about 28% and 3%, respectively. At all India basis also, the carbon sequestration is projected to increase by about 1% in 2030 A1b scenario. Cocoa-arecanut also is a good system for carbon sequestration with a potential to sequester 5 to 7 Mg CO_2 ha^{-1}. $year^{-1}$. The biomass, carbon stock and carbon sequestration in cocoa varied in relation to age and canopy managment.

Reduced emissions

1. In terms of global warming potential (GWP), a reduction of 27% was observed in system of rice intensification despite an increase in nitrous oxide emission. Direct-seeding of rice (DSR) and system of rice intensification (SRI) could be potential options for reducing methane emission. Blue green algal systems could reduce global warming potential from flooded rice soils at the levels of greenhouse gas production, transport and oxidation. These biofertilizers minimized the GHG emissions from flooded paddy apart from their ability to supply nitrogen to the crop.
2. In dairy sector, methane emission from fresh dung of indigenous breeds (Tharparker and Sahiwal) was lower than in crossbred cattle and Murrah buffaloes. The feed additives like fenugreek and mustard were able to decrease the methane levels. Indigenous technical knowledge and use of soaked oil cakes in wheat straw based diet is also able to reduce enteric methane production in cattle and buffaloes.

Vulnerability analysis

1. Among the 11 coastal districts of Tamil Nadu, Ramnad and Nagapattinam are most vulnerable to climatic change. Among all the 30 districts, the vulnerability to climate change is very high in the Perambalur district followed by the Nilgiris and Ramnad as compared to the other districts.

2. Analysis on the vulnerability of coastal districts of Maharashtra and Kerala to climate change from marine fisheries point of view indicated that among the five coastal districts of Maharashtra, the vulnerability index was highest for Thane (0.122) followed by Raigad (0.110). Among the nine coastal districts of Kerala, the vulnerability index was highest for Alappuzha (0.122) followed by Kozhikode (0.121) and Trivandrum (0.120).

3. It is projected that 35 villages in Raigad and Ratnagiri districts likely to be affected due to rise in sea level by 0.3 m.

4. The vulnerability index for the fisheries sector of West Bengal indicated that fisheries activity is more susceptible to climatic events. Studies on inland fisheries indicated that drought in West Bengal during 2009 affected 92% of the fish seed hatcheries due to deficit rainfall and high temperature in the state. Freshwater ponds became unusable due to salinity rise because of cyclone.

5. The vulnerability analysis on Punjab indicated Bathinda as the most vulnerable district with the overall vulnerability index of 0.66 followed by Kapurthala and Rupnagar. Ludhiana was the least vulnerable district with the overall vulnerability index value of 0.27.

Capacity building and awareness programmes

1. Scientific staff and the SRFs/RAs are trained on crop modeling, natural resource modeling and vulnerability analysis.

2. Several network-centers have conducted the awareness programme on climate change for farmers, agricultural extension workers and KVK staff.

3. Indigenous technical knowledge available in different agro-climatic zones were collected.

Out-reach activities

Policy support

1. Various scientists of the project have provided the reports on the assessment of climate change on different aspects of agriculture to the Ministry of Environment and Forests for National Communication (NATCOM) to UNFCCC.
2. The findings of the project work have been presented at various fora and communicated to stakeholders.

Infrastructure developed for climate change research

1. Under the project the controlled environmental facilities like Open Top Chambers (OTCs), Temperature Gradient Tunnels (TGTs) and Free Air CO_2 Enrichment (FACE) rings were established at some Institutions for quantifying the impacts elevated [CO_2] and temperature on crop growth, development, yield and quality.

Publications

Category	No.
Research Papers	
NAAS rated journals	86
Others	17
Popular Articles/ reports	39
Presentation in seminars, invited lectures, invited articles, etc.	124
Reports/ bulletins /book chapters	65
Pamphlets/ brochures	11
Books	6
Total	**348**

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Terminology

Scenario: A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in projections. Other terms that have been used as synonyms for scenario are "characterization", "storyline" and "construction".

Baseline/Reference: The baseline (or reference) is any datum against which change is measured. It might be a "current baseline", in which case it represents observable, present-day conditions. It might also be a "future baseline", which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.

Projection: The term "projection" is used in two senses in the climate change literature. In general usage, a projection can be regarded as any description of the future and the pathway leading to it. However, a more specific interpretation has been attached to the term "climate projection" by the IPCC when referring to model-derived estimates of future climate.

Forecast/Prediction: When a projection is branded "most likely" it becomes a forecast or prediction. A forecast is often obtained using deterministic models, possibly a set of these, outputs of which can enable some level of confidence to be attached to projections.

Storyline: a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.

Scenario family: one or more scenarios that have the same demographic, politico-societal, economic and technological storyline.

The emissions scenario and storyline

A1: A future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. This scenario family has four scenario sub groups and A1B scenario assumes a balanced mix of technologies and supply sources, with technology improvements and resource assumptions such that no single source of energy is overly dominant.

A2: A very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines

B1: A convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

B2: A world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

(Source: IPCC, 2004)

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