Annual Report 2008 - 09

ICAR Network Project on Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change

भाकृअनुप
ICAR

Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad – 500 059, Andhra Pradesh

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ICAR Network Project

on

Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change

Annual Report
2008 - 09

Co ordinating Center

Indian Agricultural Research Institute

New Delhi

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ICAR

Central Research Institute for Dryland Agriculture

Santoshnagar, Hyderabad – 500 059, Andhra Pradesh

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Coordinating Institute

Indian Agricultural Research Institute

New Delhi 110 012

Department / Division

Division of Environmental Sciences

Principal Investigator

Dr. P.K. Aggarwal

National Professor

Objectives

- To quantify the sensitivities of current food production systems to different scenarios of climatic change by integrating the response of different sectors
- To 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
- To determine the available management and genetic adaptation strategies for climatic change and climatic variability
- To determine the mitigation options for reducing global climatic changes in agro-ecosystems

Executive Summary

- Analysis on mean annual temperature trends of 47 locations spread across the country indicated increasing trend in the central and southern parts and north eastern region. While decreasing trend is observed in some parts of Gujarat, Konkan region, NW parts of Madhya Pradesh and Eastern Rajasthan.
- Experiments conducted under controlled environment conditions (FACE, TGT, OTC and portable chamber) to assess the effect of elevated temperature and CO_2 showed that a rise in atmospheric temperature reduced the biomass and yield of rice, greengram, pigeon pea, wheat and chickpea. Among the crops rice, pigeonpea and chickpea showed greater thermal stability as compared to greengram and wheat. Rice and chickpea showed greater thermal sensitivity during reproductive growth phase, while pigeonpea and greengram showed greater thermal sensitivity during ripening growth phase. Inreased CO_2 lead to higher biomass in plantation crops such as coconut, arecanut and cocoa; while reduced stomatal conductance, stomatal density and leaf surface wax leading to increased water use efficiency. However, slight reduction in polyphenols may predispose coconut and cocoa plants for pest and disease incidence in elevated CO_2 conditions. Tomato yields increased by 26.5% in elevated CO_2 (550ppm).
- 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. 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) concentrations. Influence of storage temperature from 22 to 45^{o}C on keeping quality of coconut copra and oil reduced oil percentage while it increased starch, carbohydrates and reducing sugars in copra. It also reduced the shelf life of coconut oil as indicated by increase in free fatty acids, acid value and peroxide value.
- While crops may take some time to adapt to climate change, our preliminary results showed that high thermal stress imposed on soil microorganism led to the generation of some distinct forms indicating their rapid adaptation to further extended/widened range of temperature.
- The impacts of climate change on hydrology of Belura watersheds Akola, using SWAT model indicated that under same cropping pattern and management activities, surface runoff and total sediment load, total aquifer recharge, water yield and PET are likely to increase significantly with increase in rainfall. The cost of bunding and trenching is likely to increase considerably due to additional earth work required.
- A Livestock Strain Index (LSI) for assessing thermal stress on animals is being suggested which is based on displacement of physiological reactions from the normal resting level. The displacement

of rectal temperature (Tre) and respiratory frequency (Rf) measured simultaneously helps quantifying the extent of stress in cattle and buffaloes on a universal scale of 0-10.

- Increase in oil sardine abundance along the northwest coast is attributed to increase in seawater temperature and changes in other oceanographic parameters. 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 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.
- 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.
- Preliminary results showed that Carp reared at 34ºC grew significantly faster (18.38 cg in a day) than those at 29-33ºC and 35ºC. It would take average 54-55 days for a carp to double in weight at 30ºC to 33ºC and 35ºC, but at 34 ºC it would take only 35-36 days.
- Rise in atmospheric temperature enhanced the emission of greenhouse gases such as CO_2 and CH_4 from the soil in standing crops of pigeonpea and greengram. However, elevated CO_2 enhanced the emission of GHG viz., CO_2 and CH_4 but reduced the emission of N_2O from the soil of standing crops.
- The carbon sequestration potential of coconut plantations was assessed using real time estimates and InfoCrop-Coconut simulation models. The outputs were up-scaled to state level for four major coconut growing states viz., Kerala, Tamil Nadu, Karnataka and Andhra Pradesh, which have about 90% of all India coconut area and production. Simulation results indicated that the carbon sequestered and stored in stem in coconut plantations in four states is to the tune of 0.732 million tonnes of carbon every year. These suggest that coconut has a vast carbon sequestration potential, which can further go up if all aspects of carbon sequestration are taken into consideration.
- In diary sector, methane is emitted in expired air normally at much lower rates than that appear in an eructation. The content of methane occasionally rises to more than 0.2% in expired air during an eructation from an average concentration of 0.05+0.02%. The numbers of eructations were observed to increase during post feeding period. Methane emissions of crossbred cows were measured and related with milk yield/day. High milk producing cows were observed to emit more methane than low producing cows. The methane emission from fresh dung of indigenous breeds (Tharparker and Sahiwal) was lower than in crossbred cattle and Murrah buffaloes.

- It is estimated that annual CO_2 emission of marine fishing boats in India was 3.6 million tonnes during 2005-2007. It was found that the mechanized boats emitted 1.67 tonnes of CO_2 per tonne of fish catch, and motorized boats with outboard engine emitted 0.48 t CO_2 per t of fish catch. Among the mechanised 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 tonne of fish caught has increased by 64% in a period of 25 years.

Signature of the Principal Investigator

Name : P.K. Aggarwal

Designation: Network Coordinator and National Professor

Specific Objectives of the Individual Centers

Indian Agricultural Research Institute, New Delhi

- To assess the impact of elevated temperature and CO_2 on growth, yield and quality and input resource utilization efficiency of rice, greengram, pigeonpea, wheat and chickpea.
- Assessing the stage specific growth and yield response of rice, greengram, wheat and chickpea to elevated temperature.
- Adaptation strategies to minimize the climatic risk in different crops through crop / varietal selection, fertilization, irrigation and planting scheduling etc.
- Assessing impact of climate change on pest dynamics and crop-pest interactions and linking pest population dynamics simulation models with InfoCrop model.
- To assess the impact of elevated temperature and carbon dioxide on emissions of GHGs and preparation of inventory of CO_2 emission from crop residue burning and their mitigation from soils.
- Assessing the impact of high temperature on evolution/adaptation of microbial population.

Central Research Institute for Dryland Agriculture, Hyderabad

- To validate Info-Crop model for key food crops in different regions of Andhra Pradesh.
- To evolve operational contingency plans for temperature and rainfall related risks.
- To assess the response of important rainfed crops to elevated CO_2 levels in terms of growth and seed yield.
- Impact of elevated CO_2 and temperature on host-herbivore interactions.

Central Plantation Crops Research Institute, Kasaragod

- Effect of elevated temperature and CO_2 on response of coconut, arecanut and cocoa seedlings.
- Adaptation strategies for coconut plantations to climate change scenarios in different agro-climatic zones.
- Impacts on quality of post harvest produce.
- Carbon trade potential of new coconut plantations as mitigation option.

Indian Institute of Horticultural Research, Bangaluru

- To study the effects of elevated CO_2, temperature, water stress on growth, water use efficiency, quality and yield of tomato and onion.

- To correlate prevailing climatic conditions to phenology, crop performance and quality of grape fruits and wine from different grape growing regions.
- To assess the impact of climate change on onion and tomato using validated Info Crop model and working out adaptation strategies and assessing vulnerability of these crops under different agro-climatic regions.

CSK Himachal Pradesh Agricultural University, Palampur

- To simulate the impacts of different scenarios of climate change on major crops of H.P. and to quantify the suitability of various agronomic measures for adaptation to climate change.
- Socio-economic surveys on honey bee's habitat at different elevation zone H.P. to asses climate change and Monitoring the phenology of crops, perennial crop viz. apple and stone fruits in different elevation zone of H.P.
- Climate Change and medium range weather forecasting literacy among stakeholders.

Central Soil and Water Conservation Research and Training Institute, Dehradun

- To provide first estimate of impact of climate change (runoff, soil loss) on important commodities of selected watersheds of India based on literature review and expert judgment.
- To calibrate and validate AVSWAT/Info Crop model for runoff, soil loss for key food crops in different Watersheds of the country.
- To simulate the impacts of different scenario of climate change (runoff and soil loss) on crop production through GLP/optimization.
- To quantify the suitability of various Watershed Management Measures for adaption to climate change (runoff and soil loss).

ICAR Research Complex for Eastern Region, Patna

- To calibrate and validate Infocrop model for key food crops in different agro climatic regions of Bihar.
- To simulate the impacts of different scenarios of climate change on crop production in Bihar.
- To quantify the suitability of various agronomic and land and water management measures for adaptation to climate change.
- To develop integrated modeling framework for coupling hydrologic model with crop water demand, water allocation and socio-economic models.

National Dairy Research Institute, Karnal

- To study the thermal stress mitigation in cattle and buffaloes.
- To measure influence of milk production level on methane emission from dairy animals.
- To document methane mitigation on the basis of Indigenous Technical knowledge.
- To study the adaptation of livestock to CC: Role of HSP's.

Central Marine Fisheries Research Institute, Cochin

- To conduct basic, applied and strategic research for quantifying the region – specific vulnerability of Indian marine fisheries to increasing climatic variability and climate change;
- To develop adaptation strategies for minimizing their negative impacts; and
- To identify mitigation strategies.

Central Inland Fisheries Research Institute, Barrackpore

- Development of models for predicting fish species richness of Indian River in relation to climate change scenarios.
- Investigate fish growth and reproduction competence under simulated condition using climate change scenarios.
- Analysis of the impact of climate change on inland fisheries and their livelihood and development and selection of appropriate adaptive fish culture practices and fish species.
- Use of GIS for the organization and display of spatial data on water resources of vulnerable area and combining a range of demographic, economic, environmental and climate data for developing on predicting models development.

Tamil Nadu Agricultural University, Coimbatore

- To develop optimal land use pattern for different ACRs using Multi-Goal Linear Programming (MGLP) with inputs from.
  - Vulnerability Index (VI) and
  - Crop models
- To prepare an insurance chart for each of major agro climatic zone of Tamil Nadu based on premium linking vulnerability of major crops due to climatic change.
- To provide training to all other participating centres in the software on MGLP and vulnerability index developed by TNAU centre.

Executive Summary by Different Centres

Indian Agricultural Research Institute, New Delhi

- Rise in atmospheric temperature reduced the biomass and yield of rice, greengram, pigeon pea, wheat and chickpea. Among the crops rice, pigeonpea and chickpea showed greater thermal stability as compared to greengram and wheat. Among the crops, rice and chickpea showed greater thermal sensitivity during reproductive growth phase, while pigeonpea and greengram showed greater thermal sensitivity during ripening growth phase.
- Contrary to rise in temperature, elevated CO_2 level in the air enhanced the photosynthesis, leaf area index, biomass and seed yield of rice, greengram, pigeonpea, wheat, chickpea and sunflower markedly.
- Protein content of wheat, greengram and chickpea seeds increased marginally with rise in temperature, whereas the same decreased marginally with rise in CO_2 level. Starch content however, showed reverse trend under elevated temperature and CO2 in wheat grain. Oil content of sunflower seed increased markedly under elevated CO_2 condition.
- Rise in atmospheric temperature enhanced the emission of N_2O from the soil of standing crops of pigeonpea and greengram. However, elevated CO_2 enhanced the emission of CO_2 but reduced the emission of N_2O from the soil of standing crops. There was also significant reduction in soil nitrate content under FACE condition.
- The exposure of *Pseudomonas fluorescens* to high temperature (35^0C) for 200,000 generations led to its adaptation in the form of widening of thermal niche.
- Increase in atmospheric temperature manifested reduction in larva population of maize stem borer, which in turn showed slight reduction in loss of maize yield under infested condition.

Central Research Institute for Dryland Agriculture, Hyderabad

- InfoCrop model was validated for Sorghum crop in Anantapur and Palem stations of ANGRAU. The observed and simulated yields were related and the R^2 values for Anantapur and Palem are found to be 0.84 and 0.64. A yield reduction of 8%, 18% and 30% during the years 2020, 2050 and 2080 respectively was noticed at Anantapur due to climate change. At Palem the percent reduction was of the order of 2.2, 5.1 and 9.7 in the years 2020, 2050 and 2080 respectively.
- Mean annual temperature trends of 47 locations spread across the country indicated increasing trend in the central and southern parts and NE regions. While decreasing trend is observed in some parts of Gujarat, Konkan region, NW parts of Madhya Pradesh and Eastern Rajasthan. From the annual climate water balance studies at different locations across the country, shifts in climate types over the years have been worked out. Many locations exhibited shift towards drier climate in the recent past.

- Changes in crop water requirement (CWR) of wheat crop due to anticipated climate change scenario have been computed. It has been observed that on an average an increase in CWR of 2.7% in the year 2020 and 5.7% in the year 2050 was observed in the majority of wheat growing region of India.

- Differential response of two sorghum varieties viz., SPV-1616 and M 35-1 to elevated CO_2 was observed. With doubling of CO_2, the increment in the total biomass of M 35-1 was by 13% and seed yield by 133% as compared with ambient chamber control. Under similar conditions, the total biomass of SPV-1616 improved to the extent of 14% and seed yield by 17%. The improvement of partitioning efficiency in M 35-1 with elevated levels of CO_2 was found to be significant when compared with SPV-1616. M 35-1-the sorghum variety with better drought tolerance and less partitioning efficiency at ambient condition responded significantly to elevated CO_2 levels for seed yield and harvest index. However, under similar conditions better efficient high yielding sorghum variety SPV- 1616 responded marginally to elevated levels of CO_2.

- High CO_2 levels adversely affect the quality of foliage and increased the RCR of larvae for longer period on groundnut to produce less fecund *S.litura* through generations. Suggesting the net damage by *S.litura* on groundnut will be less under elevated CO_2 atmosphere. The increased consumption is offset by slower development and reduced fecundity. The results are to be revalidated for their conformity.

Central Plantation Crops Research Institute, Kasaragod

- Elevated CO_2 increased net photosynthetic rates and dry matter and increased water use efficiency in coconut, arecanut and cocoa. Reduction in stomatal density and increase in cuticle thickness due to elevated CO_2 also have contributed for this trend. However, slight reduction in poly phenols may predispose coconut and cocoa plants for pest and disease incidence in elevated CO_2 conditions.

- Elevated temperature reduced net photosynthetic rates in coconut but increased that of arecanut and coconut. Results indicate that the elevated CO_2 and temperature influence physiology and biochemistry of coconut, arecanut and cocoa plants. Varietal differences in response were also observed.

- The field studies conducted indicated that soil moisture conservation is one of the potential and important adaptation strategies to reduce the climate change impacts on coconut plantations particularly in water scarce/limited conditions.

- Influence of storage temperature on keeping quality of copra and oil was studied in the context of projected increase in temperature due to climate change. Copra was stored for six months and oil was stored for eight months at several temperatures. Quality analysis indicated that increase in storage temperature from 22 to 45 ^{o}C reduced oil percentage while it increased starch, carbohydrates and reducing sugars in copra. Apart from this, during storage, concentration of reducing sugars, starch and carbohydrates increased while oil and protein reduced. Similarly, increase in storage temperature reduced the shelf life of coconut oil as indicated by increase in free fatty acids, acid value and peroxide value. It can be concluded from the results that climate change will alter the quality of copra and coconut oil during storage and the shelf life of copra and coconut oil is likely to reduce if the current storage practices are continued.

- The carbon sequestration potential of coconut plantations was assessed using real time estimates and Info Crop-Coconut simulation models. The outputs were up-scaled to state level for four major coconut growing states viz., Kerala, Tamil Nadu, Karnataka and Andhra Pradesh, which have about 90% of all India coconut area and production. Simulation results indicated that the carbon sequestered and stored in stem in coconut plantations in four states is to the tune of 0.732 million tonnes of carbon every year. These suggest that coconut has a vast carbon sequestration potential. These values can dramatically go up if all other aspects of carbon sequestration are taken into consideration.

Indian Institute of Horticultural Research, Bangaluru

- Response of tomato cv. Arka Ashish to elevated CO_2 (550ppm) was studied in Open Top chambers. There was an average increase of 25% in photosynthesis rate during different stages of the crop. A yield increase of 26.5% was observed at elevated CO_2 concentration compared to chamber control. Yield increase was mainly due to the increase in number of fruits per plant. Quality parameters were also studied. There was no increase in the lycopene and carotenoid content at elevated CO_2 compared to chamber control. Antioxidants were higher at elevated CO_2 concentrations.
- In the study on effect of flooding on onion cv. Arka Kalyan, there was 75.0 to 86.0% reduction in leaf photosynthesis, 28.0 to 46.0% in total plant fresh and 26.0 to 47.0% in dry mass production under flooding in onion. The leaf area reduction of 25% and 51% was observed in once and continuously flooded plants, respectively. The leaf senescence was also more in the flooded plants. The bulb initiation stage was found to be sensitive as the continuous flooding at this stage resulted in maximum reduction in bulb size (27.2%) and bulb yield (48.3%).
- The data on days taken for different phenological stages showed that there were differences in days taken for veraison and harvest maturity for cv. Cabernet Sauvignon and Shiraz from different grape growing areas. The total crop duration was highest in Bangalore and least in Bijapur.
- The relationship of mean maximum and minimum temperatures during veraison to fruit maturity with peel anthocyanin, total phenol, total flavonoids and acidity content showed a negative relationship in the cv. Shiraz. The increase in both maximum and minimum temperatures caused reduction in anthocyanin content at harvest. The relationship of temperature was stronger with peel anthocyanin content compared to other quality parameters. Indicating that the development of anthocyanin is more influenced by the increases in temperature under climate change conditions.

CSK Himachal Pradesh Agricultural University, Palampur

- Simulated impact of elevated CO_2 levels of 420 ppm and 470 ppm on maize crop under potential conditions and rainfed recommended condition showed a nominal increase of 3.0% to 8.1% only.

Middle of June proved to be the best planting window for maize crop at Palampur in present climate and under elevated CO_2 and temperature conditions.

- Temperature rise by 1°C and 2°C and reduction in rainfall caused decrease in maize yield by 2 to 10%.
- In wheat, results indicated that increase in yield with elevated levels of CO_2 to the tune of 4.9 to 7.3% on early sown conditions i.e 15th October.

Central Soil and Water Conservation Research and Training Institute, Dehradun

- Spatial information viz, longitude, latitude, altitude, Climatic parameters viz rainfall, radiation index, evaporation, runoff, moisture index, aridity index, precipitation deficit etc. have been generated for each watersheds under study using daily weather data of thirty years extracted from nearby meteorological stations through best possible spatial interpolation.
- In order to assess the impacts of climate change on hydrology and crop production of Belura watersheds Akola, monthly projections for the period of 2071-2100 and base line prediction of 1961-1990 from the Hadley Centre's general circulation model (HadCM3) appropriately downscaled by PRECIS model run for Indian condition (IITM, Pune) under the scenarios representing intermediate emissions (A2a, CO_2=867 ppm) were used to run SWAT and Info Crop model.
- The crop databases used are as per the default database provided in SWAT model with some modifications based on available literatures. Heat units were exactly input as per the crop physiological needs (derived from InfoCrop to maintain parity in simulation). Under the same cropping pattern and management activities, surface runoff and total sediment load, Total aquifer recharge, water yield and PET are likely to increase by 200.6%, 322.6%, 48%, 118% and 13% while ET is likely to reduce by 8% respectively under projected condition with increase in rainfall by 48.7%.
- InfoCrop was run with base line (1961-1990) and projected scenario (2071-2100) for three major crops of Belura watersheds Akola. Sorghum and Cotton crops are likely to be benefitted under projected condition with an increase in yield by 183 and 103% respectively. The inferences drawn are subjected to correction considering current and changing insect pest damage scenario, likely change in crop management practices, changing soil status every year under higher rainfall etc.
- The cost of bunding and trenching has been assessed as per the projected increase in the rainfall. It is observed that about 17 per cent additional earth work in bunding (contour or graded) will be required if the one day maximum rainfall increases by 20 percent like wise about 32.9 percent additional earth work with increase in one day maximum rainfall of 40 percent and about 80 percent additional earthwork with increase in rainfall by 100 percent is projected. Similarly the earth work of trenching is projected to be 20 percent more with 20 percent increase in daily rainfall and 40 percent more with 40 percent increase in daily rain fall. Thus the increase in earth work is directory proportional to the increase in daily rainfall.

ICAR Research Complex for Eastern Region, Patna

- For medium duration variety of rice, an increasing trend in grain yield was observed till 2050 scenario for all locations except Pusa. Short duration (Unirrigated) variety (Saket-4) shows an increase in yield for 2020 at all stations. Long duration variety shows an increase upto 2050 at Madhepura and Patna while it decreases at Pusa and Sabour from the simulated yield of baseline.
- For timely sown wheat, only Pusa location shows a slight increase of 3% for 2020 scenario, rest of the locations show a decrease in yield. Decreasing trends have been observed for late sown wheat at all stations for all scenarios.
- The rabi maize yield shows increase under all scenarios for all locations, while kharif maize shows a decline in yield under all scenarios. Grain yield of Chickpea under different scenarios for Pusa location shows an increase from the baseline upto 2050 (15% for 2020, and 7% for 2050).
- 7 days advanced sowing is predicted to be beneficial for rice, maize and chickpea crops and 7days advanced sowing combined with higher nitrogen dose in wheat shows increase in yield.

National Dairy Research Institute, Karnal

- A Livestock Strain Index (LSI) for assessing thermal stress on animals is being suggested which is based on displacement of physiological reactions from the normal resting level. The displacement of rectal temperature (Tre) and respiratory frequency (Rf) measured simultaneously helps quantifying the extent of stress in cattle and buffaloes on a universal scale of 0-10. Depression in wet bulb (DWB) may be used as an index for adiabatic cooling in different parts of India during dry hot summer.
- The study on Sahiwal and Holstein Friesian crossbred (Karan-Fries) heifers was carried out to find out the pattern of expression of HSP72. The basal level of HSP72 protein was higher in lymphocytes of Sahiwal (1.76±0.30 ng/µg) than that in lymphocytes of Karan-Fries (1.03±0.27 ng/µg). HSP72 protein level increased due to thermal exposures.
- Methane is emitted in expired air normally at much lower rates than that appear in an eructation. The content of methane occasionally rises to more than 0.2% in expired air during an eructation from an average concentration of 0.05+0.02%. The number of eructations were observed to increase during post feeding period.
- Methane emissions of crossbred cows were measured and related with milk yield/day. High milk producing cows were observed to emit more methane than low producing cows.
- The methane emission from fresh dung of indigenous breeds (Tharparker and Sahiwal) was lower than in crossbred cattle and Murrah buffaloes.

Central Marine Fisheries Research Institute, Cochin

- Impact of increase in small pelagic abundance on the ecosystem of northwest coast: Increase in oil sardine abundance along the northwest coast is attributed to increase in seawater temperature and changes in other oceanographic parameters. 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 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.

- Temporal changes in the oceanographic parameters and fish catch along the Kerala coast: Monthly average data on oceanographic parameters for the years 1958-2008 along Kerala coast showed significant changes in the trend and increase in anomalies. Analysis of quarterly moving averages of SST, Salinity, Rainfall, Meridional Wind, Zonal Wind and Sea Level showed good correlation with lag 3 of quarterly catches of oil sardine and Indian mackerel. The result will lead further into predicting fish catches.

- Effect of seawater temperature on growth, decay and species composition of phytoplankton: Laboratory experiments on the effect of seawater temperature on seven marine phytoplankton species showed that the microalgae grew faster at higher temperature (29^{o}C), but the decay set-in earlier than at lower temperature (24^{o}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.

- Vulnerability of coastal fishing villages of Maharashtra to sea level rise: In Maharashtra, 75 coastal fishing villages are located within 100 m from the high tide line. After geo-referencing these villages, three different Sea Level Rise scenarios were created to determine critical area adjacent to the coast, likely to be submerged. Base mark (0 m), points at 0.3 m, 0.6 m and 1.0 m were obtained through Google Earth Professional software to calculate the perimeter and area for three SLR scenarios. Consolidation of all the maps to identify vulnerable coastal fishing villages in Maharashtra is under progress.

- Estimation of carbon footprint by marine fishing boats: It is estimated that annual CO_2 emission of marine fishing boats in India was 3.6 million tonnes during 2005-2007. It was found that the mechanized boats emitted 1.67 tonnes of CO_2 per tonne of fish catch, and motorized boats with outboard engine emitted 0.48 t CO_2 per t of fish catch. Among the mechanised 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 tonne of fish caught has increased by 64% in a period of 25 years.

Central Inland Fisheries Research Institute, Barrackpore

- Out of the 14 major river systems studied in India, four rivers are predicted to lose more than 7% of fish species under climate warming scenario as determined from the model developed.
- Carp reared at 34ºC grew significantly faster (18.38 cg in a day) than those at 29ºC, 30ºC, 31ºC, 32ºC 33ºC and 35ºC. It would take average 54-55 days for a carp to double in weight at 30ºC to 33ºC and 35ºC, but at 34 ºC it would take only 35-36 days.
- Apart from the other source and variables of vulnerability for district south 24 Parganas, W.B. five sources which are direct or indirectly related to the fisheries sector of South 24 Parganas expressed only 11.11% of total District's vulnerability. The fisheries sector contributing 26.54%, the occupational index contributing only 15% and the geographical location contributing 22.12% of the expressed vulnerability.
- Water resources of south 24 Parganas district were delineated using IRS 1D PAN + LISSIII merged satellite data using supervised classification and visual interpretation. Most of the water bodies are below 10 ha. Digital elevation Model was generated from SRTM (Shuttle Radar Topographical Mission) of 90m spatial resolution data. The extent of land that will be submerged under scenarios of sea water rise in Sagar island, Sunderbans was estimated.

Tamil Nadu Agricultural University, Coimbatore

- The climate change projection indicates that there is a possibility for increase in rainfall from 2075 onwards in almost all the agro climatic zones of Tamil Nadu. Larger shift in rainfall quantum is expected in Western and southern agro climatic zones which are exhibiting semiarid tropical climate in the current status. Maximum and minimum temperatures exhibit increasing trends in all zones of Tamil Nadu. However, warming is not uniform among the different zones. Projections indicate that the climate in all zones of Tamil Nadu will continue to warm, possibly by as much as 4.6°C by the end of the century (2100) above mean annual temperature (1961-1990).
- Compared to maximum temperature, minimum temperature is increasing more and the projected increase in minimum temperature for the year 2071 is from 2.51 to 2.71 °C over Tamil Nadu.
- Effect of three different climate change scenarios for 2020, 2030 and 2050 on the crop productivity and water requirement for major crops are estimated in the DSSAT model (Decision Support System for Agro Technology Transfer) was incorporated in the MGLP model to find the optimal allocation of land use. The results indicate that introducing all constraints simultaneously, the maximum rice production will decline to 6.65, 6.78 and 6.16 million tonnes in 2020, 2030 and 2050 respectively from the current level of 7.47 million tonnes.
- DSSAT and INFOCROP models have been validated and it shows that these models predict the yield at acceptable levels when comparison with the actual observation. Impact of climate change on crop productivity of maize, cotton, red gram and rice indicated that the crop yields will go down due to increase in temperatures and variation in rainfall.

Detailed Progress Report

INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI

Objective 1: Assessing the impact of elevated temperature and CO_2 on growth, yield and quality and input resource utilization efficiency of rice, greengram, pigeonpea, wheat and chickpea using TGT and FACE and OTC facilities.

1.1. Impact of elevated temperature on growth and productivity of crops

Two important wet season crops (greengram and pigeonpea) and two dry season crops (wheat and chickpea) were grown in temperature gradient tunnels (TGT) equipped with automatic temperature sensors along the tunnel and continuous data logging system to assess the impact of rising temperature on growth, yield and quality traits of these crops. Continuous increases in temperature under TGT caused early flowering and maturity with marked reduction in leaf area index (LAI), which in turn manifested gradual reduction in biomass and economic yield of the crops. The reduction in yield was mainly attributed to marked reduction in both the number of sinks per plant and 1000seed/grain weight. Among the crops, wheat showed higher extent of reduction in grain yield by increasing temperature (thermal sensitivity) as compared to pigeonpea and chickpea. Reproductive growth showed greater thermo-sensitivity as compared to vegetative growth in almost all the crops tested (Fig.1).

1.2. Impact of elevated CO_2 on growth and productivity of crops

Two kharif crops (greengram and pigeonpea) and two rabi crops (wheat and chickpea) were grown under ambient (380 ppm) and enriched CO_2 (550ppm) conditions using Free Air Carbon dioxide Enrichment (FACE) facility to assess the effect of increased CO_2 level on growth and yield of aforesaid crops. Crops gown under high CO_2 condition recorded higher leaf area index (LAI) throughout the crop growth season, while failed to show any effect on crop phenology (Fig.2). Both wheat and chickpea grown under elevated CO_2 condition recorded higher photosynthesis rate and lower stomatal conductance throughout the crop growth period (Fig.3). Elevated CO_2 enhanced the biomass and yield of greengram, pigeonpea, chickpea and wheat substantially (11-22%). Among the crops, chickpea manifested highest degree of increase in yield followed by wheat and greengram, while biomass was increased to maximum extent in wheat as compared to other crops. Enhancement in crop yield was attributed to marked increase in number of sinks and seeds/grains per sink. Harvest index was however least affected by CO_2 fertilization in almost all the tested crops (Fig. 4).

Uptake of nutrients (N, P & K) was also affected by high CO_2. Crop grown under elevated CO_2 condition showed better growth and also higher nutrient uptake. Under elevated CO_2 condition, uptake of all 3 major nutrients was found higher than ambient CO_2 condition (Table 1).

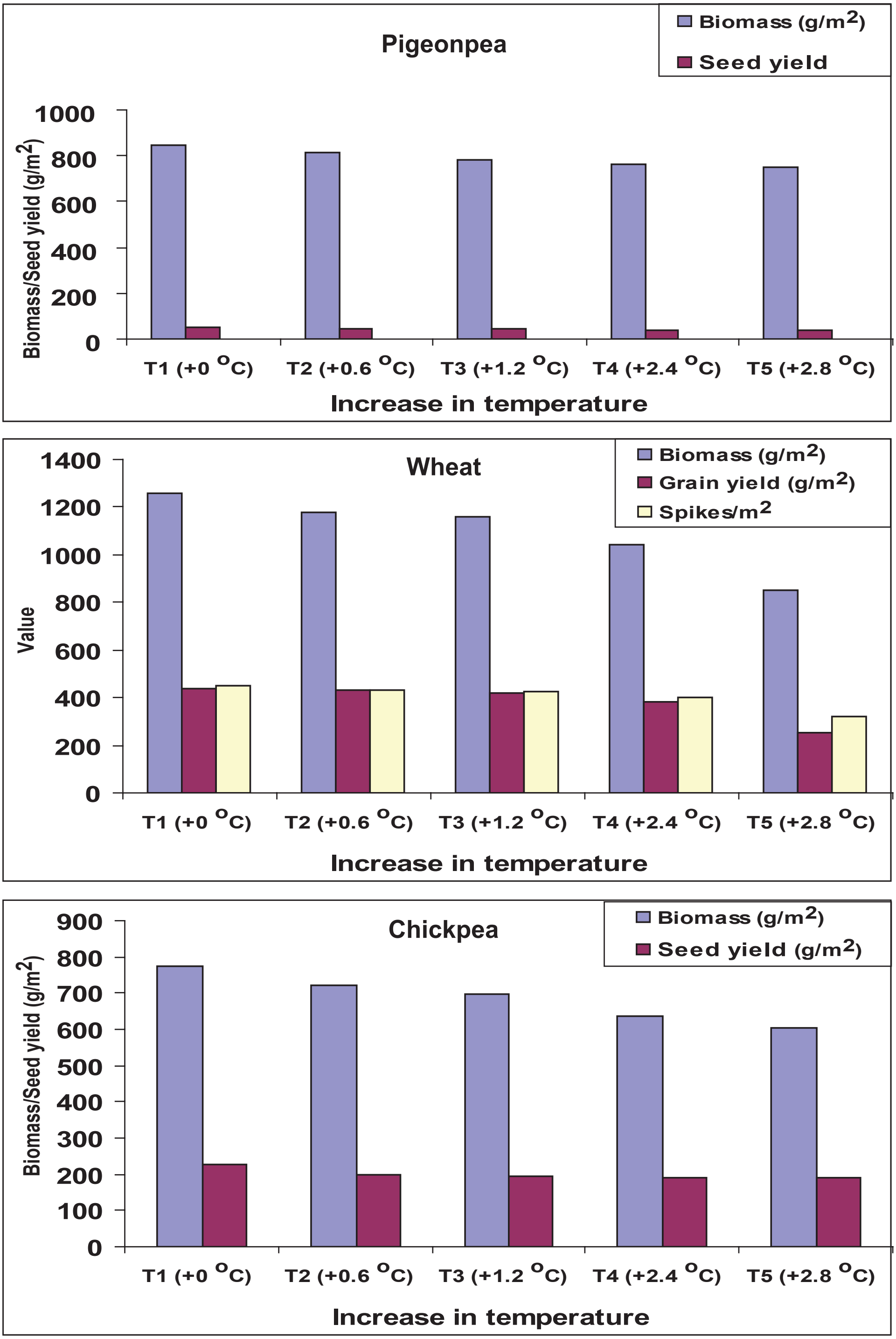


Fig. 1. Influence of rise in temperature on biomass and grain yield of crops

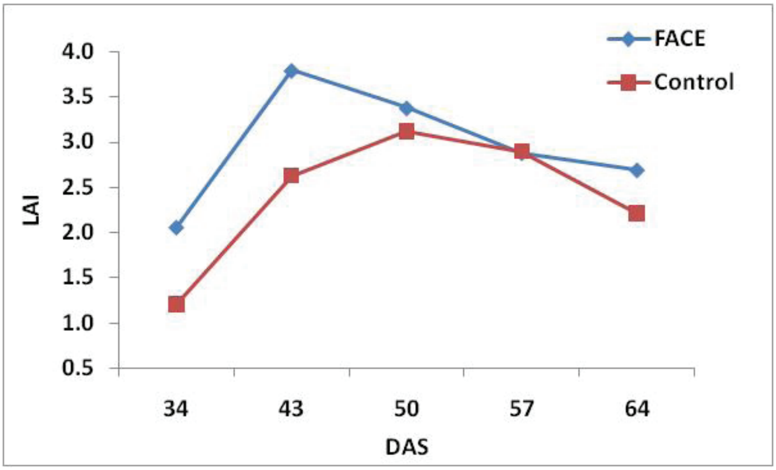


Fig. 2. Effect of elevated CO_2 on leaf area index (LAI) of green gram crop

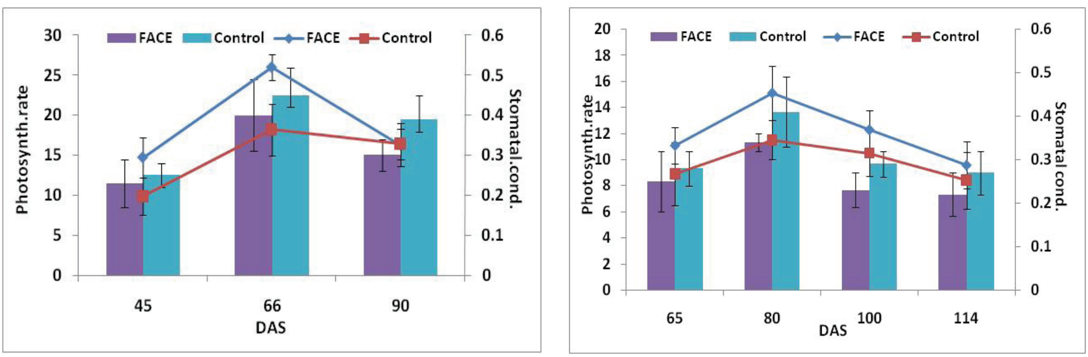


Fig. 3. Impact of elevated CO_2 on photosynthesis rate & stomatal conductance of (A) chickpea & (B) wheat crop

Table 1. Impact of elevated CO_2 on nutrient uptake in greengram crop

Nutrient	Elevated CO_2	Ambient CO_2
N (kg ha-1)	61.5	55.8
P (kg ha-1)	6.3	5.8
K (kg ha-1)	38.2	33.2

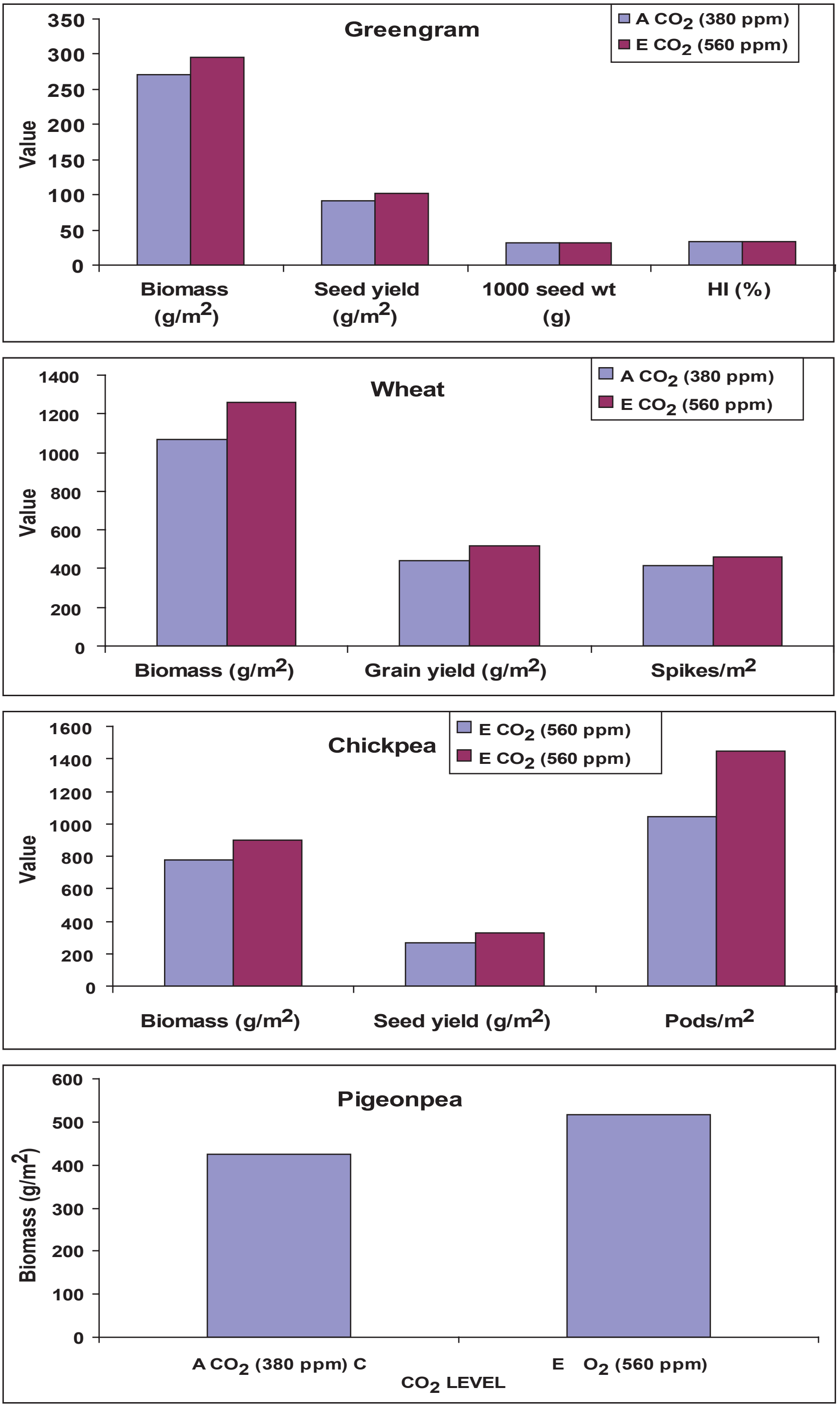


Fig. 4. Effect of elevated CO_2 on growth and yield of different crops

1.3 Effect of elevated temperature and CO_2 on rice growth and yield

Pusa Rice Hybrid-10 (PRH-10) and its both the parental lines PRR 78 and Pusa 6B were grown in large size pots (diameter 18") inside open top chambers (OTCs) and exposed to ambient CO_2 (380 µmol mol^{-1}) and high CO_2 level (600 µmol mol^{-1}) after transplantation and continued until maturity. During panicle initiation (50-55 DAT) and anthesis stage (90-95 DAT), two sets of plants were transferred for a period of ten days to another open top chambers with similar levels of CO_2 concentrations, and exposed to high temperature (+3-4°C) during day time by passing hot air inside OTC using electrical heating coils fitted at the outlets of air blowers. The level of temperature was maintained 3±0.65^{0}C by regulating the heating and speed of the air fans. The temperature was monitored and recorded regularly. After exposure to high temperature for 10 days, these plants were transferred back to ambient and elevated CO_2 levels (380 and 600 µmol mol^{-1}). Photosynthesis and carbohydrates concentration were recorded during panicle initiation and anthesis using LI 6400 photosynthesis system. Yield and yield parameters were recorded at maturity of the crop.

Rate of Photosynthesis

Elevated CO_2 exposure resulted in higher rate of photosynthesis in all three rice genotypes during panicle initiation (PI) and anthesis stages. During PI stage Pusa 6B showed highest increase (47.4%) compared to PRR 78 and PRH 10 under high CO_2 level. In Pusa 6B, there was positive effect of high temperature exposure on rate of photosynthesis in both ambient as well as high CO_2 grown plants. In all the three rice genotypes, plants exposed to higher temperature during PI and anthesis showed positive response and exhibited higher rate of photosynthesis. At anthesis stage, impact of high CO_2 was less on photosynthesis rate in Pusa 6B plants, while PRR-78 and PRH-10 plants showed increase in photosynthesis due to exposure to high CO_2 and the magnitude of increase was almost similar. PRR-78 plants exposed to high temperature during anthesis showed marginal reduction in their rate of photosynthesis compared to plants grown under normal temperature but no such effect of high temperature was observed during PI stage in this genotype. PRR-78 and PRH-10 plants showed almost similar response to high CO_2 on their photosynthetic activity (Fig. 5).

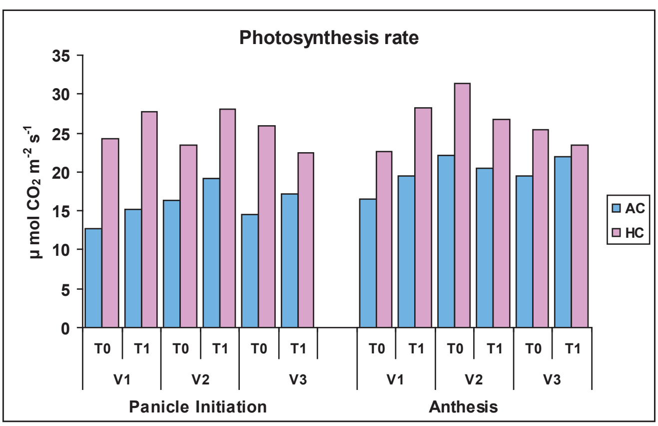
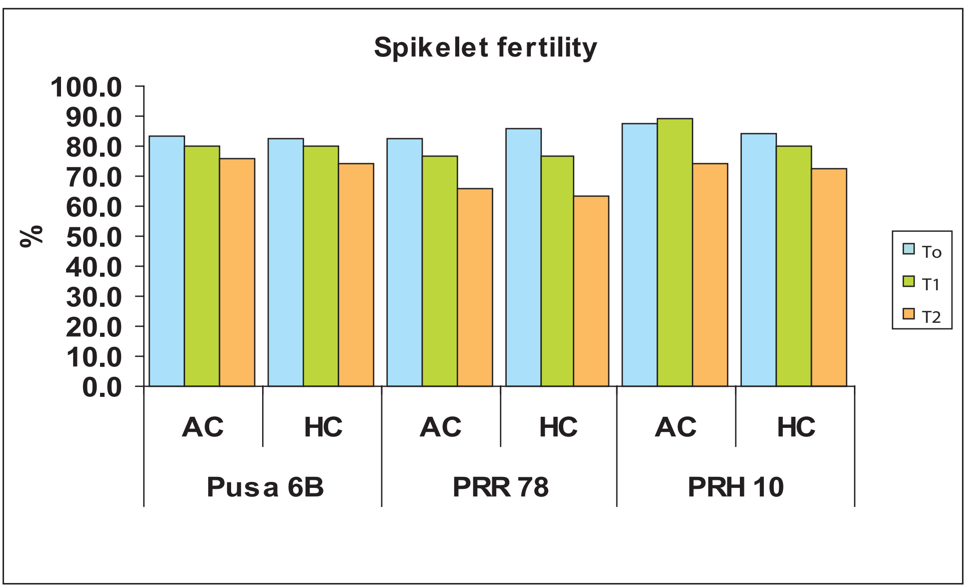


Fig. 5. Effect of high CO_2 and temperature on rate of photosynthesis of rice genotypes

Yield and yield attributes

Plants of all three rice genotypes grown under elevated CO_2 condition produced more number of tillers compared to ambient CO_2. Maximum increase in number of tillers was observed in PRR-78 followed by PRH-10 and Pusa 6B. No significant effect of high temperature exposure was observed on number of tillers. Response of CO_2 exposure was more on the plants exposed to high temperature during PI and anthesis and transferred back to normal temperature, as these plants produced more number of tillers in all the genotypes compared to plants grown continuously under normal temperature. These findings indicate positive impact of 3^0C rise in temperature on vegetative growth of rice plants.

No significant effect of high CO_2 exposure was observed on spikelet fertility in all three rice genotypes. Exposure to high temperature during PI and anthesis caused higher reduction in spikelet fertility of PRR-78 and PRH 10 and only marginal reductions (up to 10%) in Pusa 6B. Moreover, effect of high temperature on spikelet fertility was more in plants grown under high CO_2 level as compared to plants grown under normal CO_2 level (Fig. 6). All three rice genotypes showed reduction in grain yield due to high temperature exposure and PRH-10 showed highest reduction, while Pusa 6B showed less reduction both under ambient and elevated CO_2 grown plants (11 and 13% respectively). In PRR-78, the reduction in grain yield was more than Pusa 6B and less than PRH-10. Reductions in grain yield due to high temperature was more in high CO_2 grown plants both in PRR-78 and PRH-10 rice hybrid. Total plant dry weight increased significantly due to high CO_2 in PRH-10. The response of high CO_2 was more in high temperature exposed plants during PI and anthesis compared to those grown under normal temperature continuously. On the other hand, in Pusa 6B and PRR 78 plants, high CO_2 positive response was observed only in normal temperature grown plants, and the plants which exposed to high temperature during PI and anthesis showed no significant changes in their total plant dry weight.



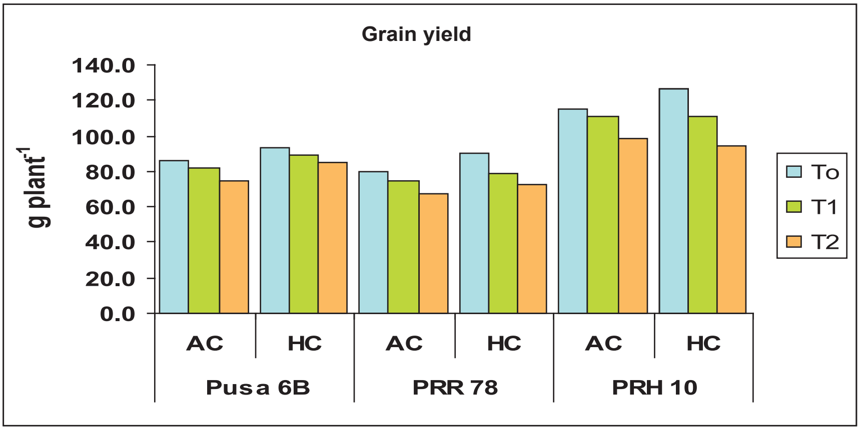


Fig. 6. Effect of high temperature and CO_2 on spikelet fertility and yield of rice

1.4. Impact of elevated temperature and CO_2 on quality characters of different crops

Gradual increases in temperature reduced the starch content in wheat grains marginally. However Protein content in the seeds of wheat, chickpea and greengram increased slightly under elevated temperature. Contrary to elevated temperature, increased CO_2 level in the atmosphere caused marginal decline in seed protein content of greengram, chickpea and wheat (Fig.7). Due to elevated CO_2, oil percent increased (5 & 15%), but protein percent decreased by 3% in sunflower (Table 2). Fatty acid composition of the oil extracted from seeds of plants grown under elevated CO_2 levels generally did not vary from that of controls except for an increase in oleic acid percent in the hybrid DRSH-1 (Fig. 8). Analysis of seed quality traits revealed that 100 seed weight increased by 50% and seed vigour improved in seeds harvested from plants exposed to elevated CO_2. However, there was varietal difference in their response with the hybrid DRSH-1 showing greater deterioration in quality traits than the variety DRSF-113.

Table 2. Impact of elevated CO_2 on yield and seed quality of two sunflower genotypes

No.	Parameter	DRSH-1		DRSF-113		CD (5%)
		Ambient	Elevated CO_2	Ambient	Elevated CO_2	
1	Biomass/plant (g)	76.6	123.5	68.4	114.9	12.83
2	Yield/plant (g)	13.2	17.93	10.2	14.9	3.09
3	Oil %	32.1	35.0	29.3	37.9	0.76
4	Protein %	19.05	18.0	18.1	17.1	0.44
5	Carbohydrate %	10.7	11.7	9.45	8.8	0.57
14	100 seed wt. (g)	2.76	4.59	3.57	5.40	0.48
13	Germination %	88.0	87.0	85.0	83.0	4.07
14	Seedling length (cm)	25.9	32.7	30.4	37.6	3.40
15	Seedling d. wt. (mg)	22.0	34.0	25.0	43.0	0.049

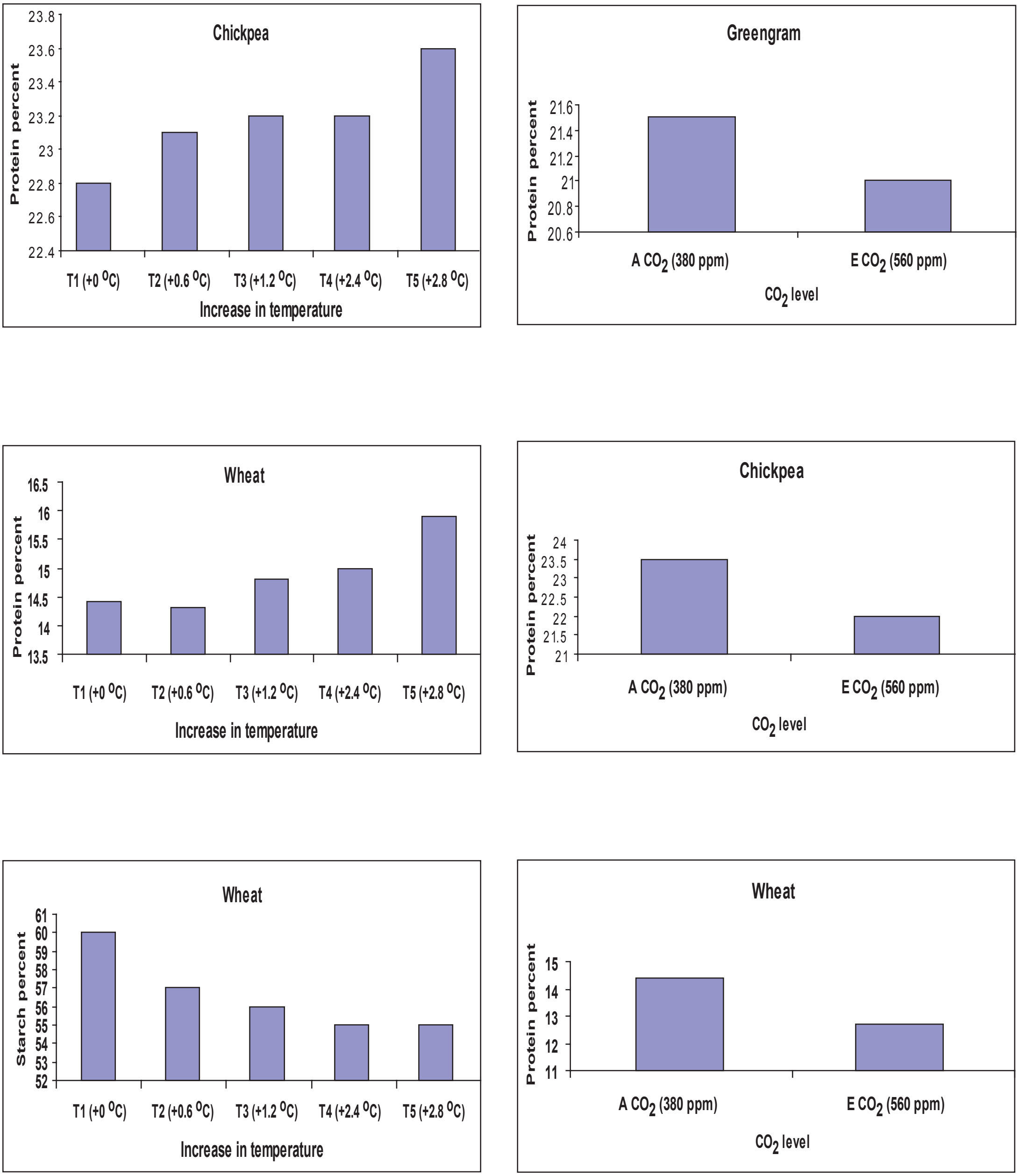
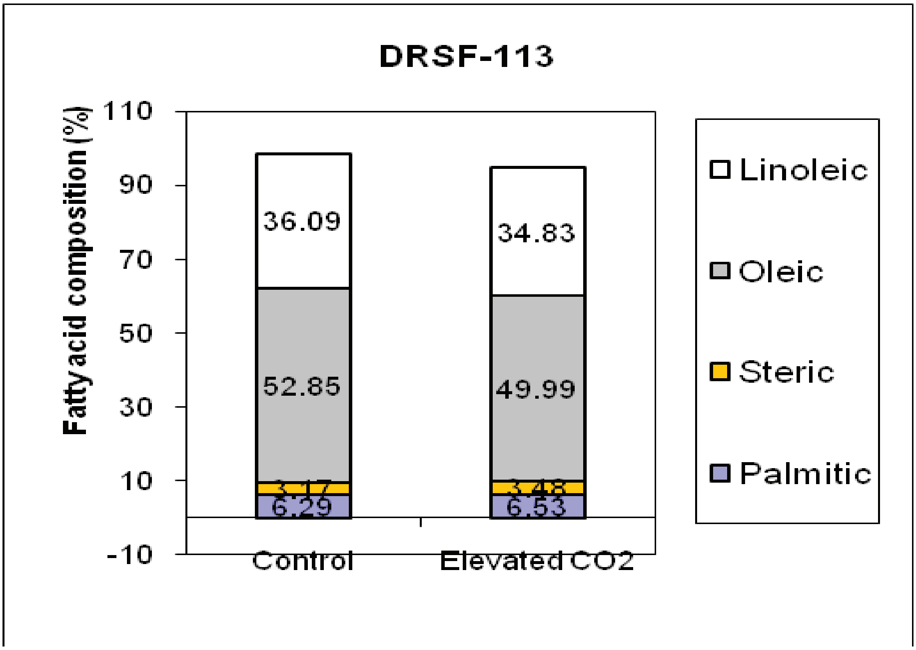


Fig. 7. Effect of high temperature and CO_2 level on seed quality of chickpea and wheat



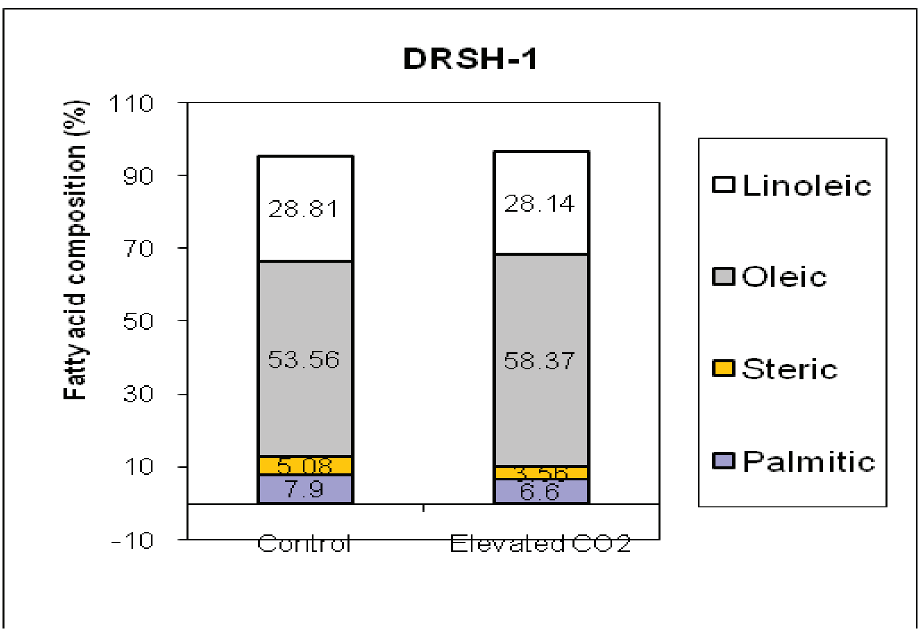


Fig. 8. Impact of elevated CO_2 on fatty acid composition of two sunflower genotypes

Objective 2: Assessing the phase specific growth and yield response of different crops to elevated temperature.

Four important crops viz., rice, greengram, pigeonpea and chickpea were subjected to high temperature stress during vegetative, reproductive and ripening growth phase to assess the impact of hyper thermal stress during different growth phases on growth and yield of these crops. The results indicated that different crops showed differential growth and yield response to high temperature stress during various growth phases. Among the crops, rice showed maximum detrimental effect of high temperature stress during reproductive growth phase followed by vegetative and ripening growth phase, while pigeonpea and greengram showed greater thermal sensitivity during ripening growth phase (Fig 9).

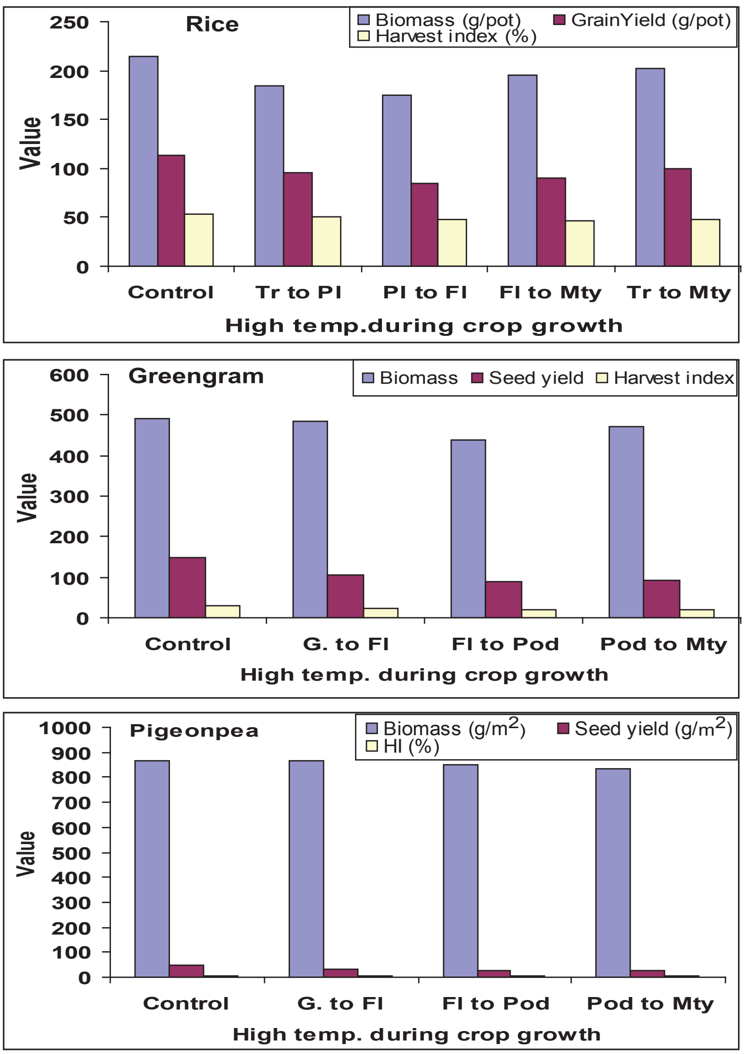


Fig. 9. Effect of high temperature (3-4^{0}C) at different growth phase on crop yield

Impact of temperature on net photosynthesis of mung bean at flowering stage

Mung bean plants (Var. PDM-139) at flowering stage were exposed to different temperature regimes either inside TGT or inside poly tunnels or inside a net house. In all treatments, air temperature varied between 28 to 40^{0}C and leaf temperature varied between 28 to 38^{0}C and PAR between 800 to 1000 µE/m^2. Net photosynthesis was measured on the second matured leaf from the top of similar plants at flowering using LICOR-6400 with an external light source of 500 µE/m^2. Net photosynthesis varied between 12.8 at 28.7^0 C to a maximum of 22.5 at 35.1^{0}and then fell to 9.8 µE/m^2/s at 40.2^{0}C. Air temperature and net photosynthesis showed a curvilinear relationship with maximum at 34^{0}C. In mung bean, photosynthesis remained higher between 31 to 37^{0}C and fell sharply below and above this temperature range (Fig. 10).

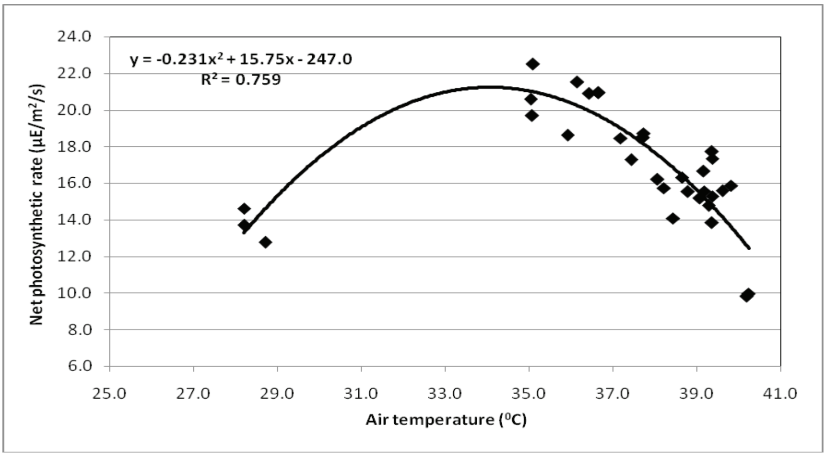


Fig. 10. Relationship between air temperature and net photosynthesis at flowering stage of mung bean plants

Objective 3. Assessing impact of climate change on pest dynamics and crop-pest using InfoCrop model.

InfoCrop-maize was coupled with holometabolous population dynamics model and coupled model was then used to simulate population dynamics of maize stem borer, *Chilo partellus* as well as crop-pest interactions. The coupled model was calibrated and validated with data, collected during 1992, on larval population of the stem borer and corresponding yield of maize hybrid 'Ganga-2'. The population dynamics model was initialized with 500 adults/ha with a sex ratio of 1:1. Thermal constants for egg, larval, pupal and adult stage were 51, 492, 45 and 20 degree days (DD), respectively. Various mortality factors were infertility (0.461), larval mortality (0.935) and pupal mortality (0.095) while fecundity was taken as 120 eggs/female. The effect of larval population on crop was simulated from 20 to 50 days after sowing (DAS).

Validated model was used to simulate effect of 0.5, 1, 1.5, 2, 2.5 and 3 ^{o}C rise in both maximum and minimum temperature compared to ambient conditions on pest dynamics as well as crop-pest interactions under Delhi conditions. For this, simulations were done for last 15 years from 1981 onwards and mean values of larval population and crop yield were derived (Fig. 11) shows validation results where observed and simulated larval population of the stem borer and corresponding observed and simulated crop yields in different datasets were closely related to each other. As the larval population increased, the crop yield decreased. Simulation of pest dynamics and crop yield for many years showed decline in maize productivity as well as in larval population of maize stem borer. Yield of healthy crop consistently declined form 5156 kg/ha at present to 3172 kg/ha with 3°C rise in daily mean temperature. Likewise yield of pest stressed crop continuously decreased from 4773 kg/ha to 2701 kg/ha with 3°C rise in daily mean temperature. Larval population of maize stem borer also depicted consistent decline with rise in temperature (Fig. 12). The pest population declined by 13.7 – 43.1% with a rise of 0.5 – 3°C over current daily mean temperature. In accordance with decline in pest population, stem borer induced yield losses also decreased. However, yield losses did not exactly corresponded with decrease in larval population, which needs to be further investigated. Although, the severity of maize stem borer may decline with global warming, but net productivity of maize is likely to reduce by the same.

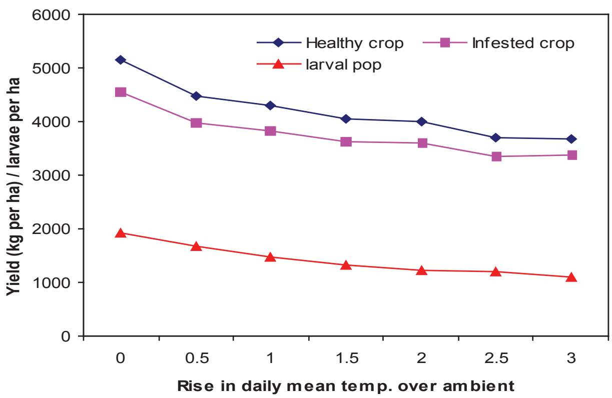


Fig. 11. Impact of temperature rise on population of maize stem borer and crop-pest interactions

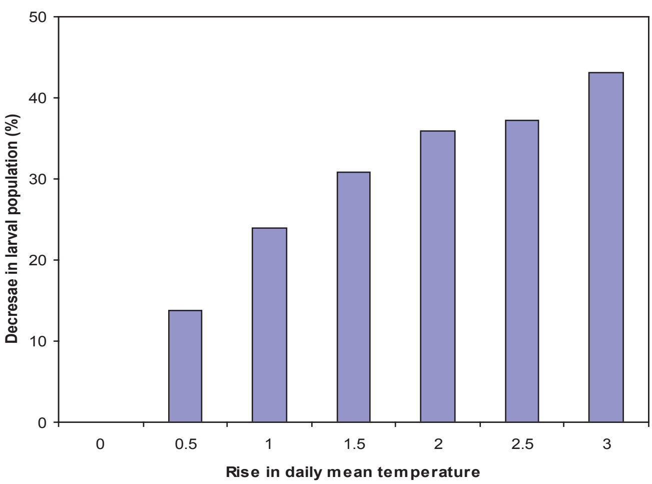


Fig. 12. Decrease in larval population of maize stem borer with rise in daily mean temperature

Objective 4. To assess the impact of elevated temperature and carbon dioxide on emissions of GHGs and preparation of inventory of CO_2 emission from crop residue burning and their mitigation from soils.

To study the impact of elevated temperature and carbon dioxide on the GHG emissions, measurement of soil nitrous oxide and carbon dioxide emissions was carried out in greengram and pigeonpea crops grown under varying thermal regimes (using TGT) and free air carbon dioxide enrichment (FACE) conditions. Emission of CO_2 from soils of standing crops was significantly higher under elevated CO_2 level (550ppm). The cumulative carbon dioxide emissions from soil under FACE increased by 17 and 21% in greengram and pigeonpea, respectively over the ambient CO_2 levels (Fig. 13). The greater soil CO_2 emission under elevated atmospheric CO_2 treatment was related to greater root biomass in the FACE rings. The nitrous oxide emission was reduced by 10 to 14% in greengram and pigeonpea, respectively under FACE over ambient CO_2 levels. There was also significant reduction in soil nitrate content under elevated CO_2 levels (Table 3).

The soil temperature varied from 30.2 to 36.5°C inside the TGT. The soil C decomposition increased under elevated temperatures of the TGT, which led to a decline in the soil OC. The cumulative carbon dioxide flux ranged from 257 to 290 µmol m^2 s^{-1} in greengram and from 313 to 382 µmol m^2 s^{-1} in pigeonpea along the increasing temperature gradient. The nitrous oxide emissions also increased significantly under elevated temperature. An increase of (2.8°C) over ambient resulted in an increase of 9 to 18% of cumulative N_2O-N in pigeonpea and greengram, respectively.

Methane emissions were measured from rice grown under elevated carbon dioxide (500±50ppm) in open top chambers. Elevated CO_2 affected N mineralization and C decomposition in submerged rice soil during the different growth stages of rice, and CH_4 emission gradually increased with the growth of rice plants. Elevated CO_2 concentration increased root dry weight by 6% at maximum tillering, 11% at flowering and 17% at maturity. Increased root weight and subsequent root exudation indirectly influence C and N cycling in soil affecting the GHG emission from soil. The methane emissions in rice increased by 7% under 500±50 ppm of elevated carbon dioxide over the ambient carbon dioxide concentrations.

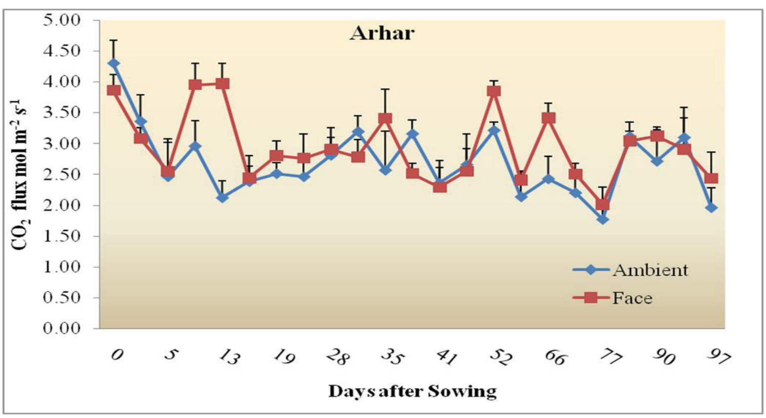


Fig. 13. Impact of elevated CO_2 on carbon dioxide emission from soil in FACE in Pigeonpea

Table 3. Impact of elevated temperature (TGT) and carbon dioxide (FACE) on nitrous oxide emission (g ha^{-1}) from soil.

	FACE		TGT	
	Ambient	**Elevated**	**Ambient**	**Elevated**
Moong	184±11	160±07	199±22	270±16
Arhar	176±08	156±05	245±13	280±09

GHG mitigation potential of neem oil coated urea fortified with melacins

A field experiment was conducted in rice crop to evaluate the GHG mitigation potential of neem oil coated urea fortified with melacins. Nitrogen was applied through prilled urea in all the treatments. Neem oil coated urea fortified with different concentration of melacins (0,5,10,20,75%) was applied along with prilled urea except in control plot. Measurements of GHGs were conducted from rice crop (var. PRH-10). Emission of N_2O-N ranged from 0.3-16.7 g /ha /d in different treatments. NOCU fortified with 10, 20, and 75% melacines reduced the N_2O-N emissions by 19, 21 and 25% respectively as compared urea. The nitrification inhibition potential of neem oil coated urea fortified with melacins was in the range of 30-40%. Correlation of meliacin content in neem oil coated urea versus nitrification inhibition activity of neem oil coated urea was found to be positive implying that there is a direct influence of meliacin content on NI activity. The inhibitors also influenced the emission of CH_4. CH_4 emission from rice ranged from 9-697 g /ha /d in different treatments. NOCU fortified with 10, 20, and 75% melacines reduced the methane emissions by 5, 11 and 18% respectively. The decrease in CH_4 emission might be due to the inhibition of CH_4 production by methanogenic bacteria. Inhibition of CH_4 production may be because of high redox potential of the soil as well as lower population of methanogenic bacteria and their activity.

Table 4: Emission of nitrous oxide and methane their total global warming potential in the rice

Treatment	Emissions from rice (kg/ha)		GWP	% Reduction in GWP
	N_2O-N	CH_4	Kg CO_2/ha	
Prilled urea	0.61	25.18	811	
urea + NOCU (0% melacins)	0.59	24.79	796	1.88
urea + NOCU (5% melacins)	0.51	24.08	754	7.03
urea + NOCU (10% melacins)	0.50	23.86	744	8.23
urea + NOCU (20% melacins)	0.48	22.51	705	13.05
urea + NOCU (75% melacins)	0.46	20.65	653	19.51

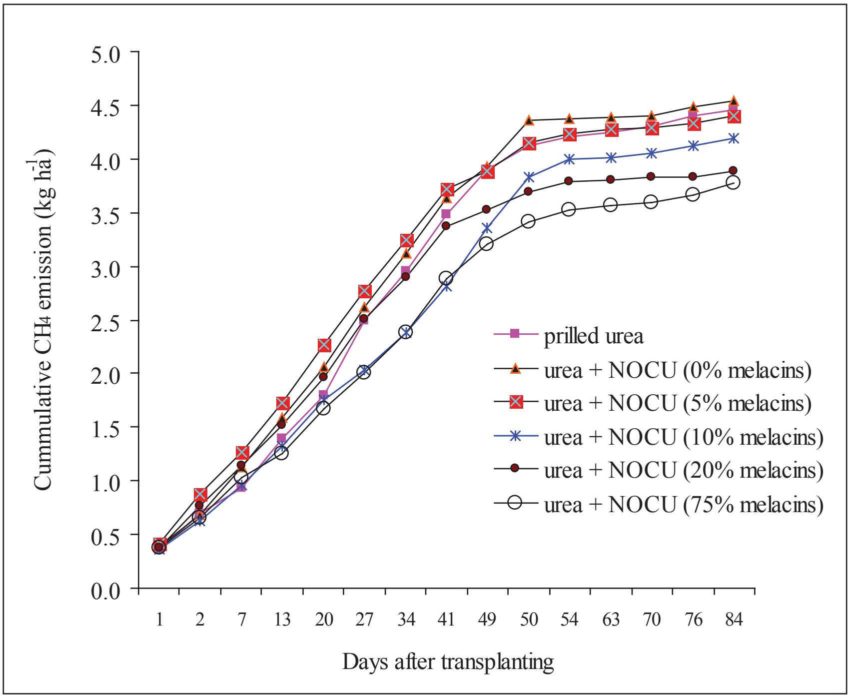


Fig. 14 A. Cumulative emission of methane from rice fields

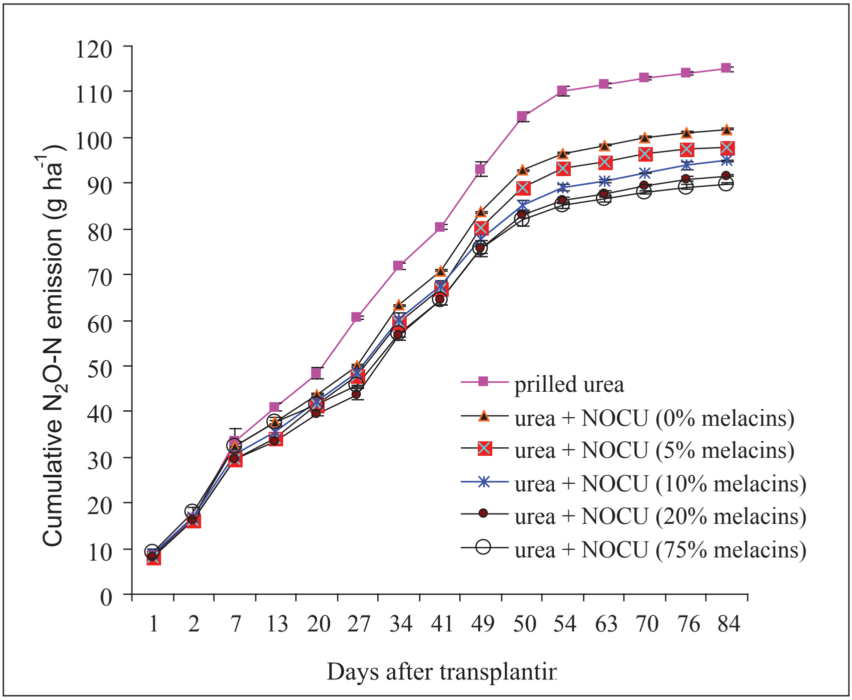
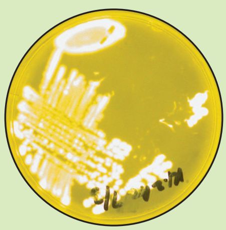


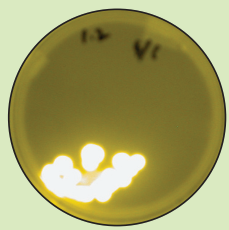
Fig. 14 B. Cumulative emission of nitrous oxide from rice fields

Objective 5. Assessing the impact of high temperature on evolution / adaptation of microbial population.

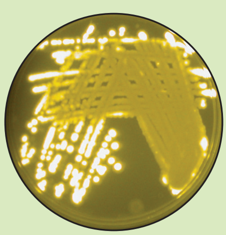
Temperature is considered as a key environmental variable, as it exerts a controlling influence on nearly all-physiological rate processes of an organism and thereby affects the growth and reproduction. Microbes are increasingly being used as a model system to test various hypothesis of evolutionary and adaptation mechanisms. Four different strains of *Pseudomonas fluorescens* (tentatively identified) namely Strain 1, 1.1, 1.2 and 2 were isolated from the chickpea rhizosphere on the King's base medium. These four strains could grow at 25, 28 and 30^{0}C and were showing good fluorescence under UV. All the strains were given the thermal shock of 35^{0}C and 40^{0}C for 24 h and out of four only one Strain i.e.1.2 showed very less growth at 35 ^{0}C, where as for rest of the strains both temperatures were found to be lethal to all the organisms. To test whether these are really the temperature resistant colonies of strain 1.2, the colonies, which could tolerate the 35^{0}C temperature were again grown at 28^{0}C (their optimum temperature) for 24h and then again tested at 35^{0}C for their growth. They could grow well again at this temperature. These temperature resistant colonies were found to have widened their thermal niche as they could grow very well at 40^{0}C as compared to the ancestral strain (which couldn't grow at 40^{0}C). The widening of the thermal niche after the thermal shock indicates that probably the organisms are trying to adapt to higher temperature by the natural selection.



Strain 1.2 growing at 28^{0}C



Strain 1.2 growing at 35^{0}C after the thermal shock



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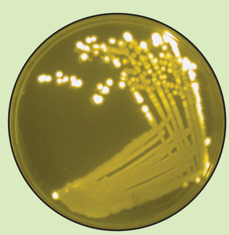


B

Strain 1.2 growing at 40^{0}C after the temperature resistant colonies (growing at 35^{0}C) were reverted to 28^{0}C and then grown at 40^{0}C (A) and temperature resistant colonies were directly grown at 35^{0}C (B)

Fig. 15. Adaptation behaviour of microorganism to high thermal stress

CENTRAL RESEARCH INSTITUTE FOR DRYLAND AGRICULTURE

HYDERABAD

Objective 1: To validate Info-Crop model for key food crops.

Experimental data of Sorghum crop yields for the years 1979 to 1985 and daily weather data of Anantapur and Palem for 1995-2006 was collected. Info-crop model output was validated at both the stations. The observed and predicted yields are presented in the (Table 5). The model under estimated the crop yields at Anantapur by 25.5 and 11.6 during the years 1981 and 83 respectively. Overall the error percentage was 8.6 (Table 5). At Palem, the model predicted the yields with overall error percentage of 11.8 (Table 6) The predicted and actual yield showed good correlation with the R^2 values of 0.84 at Anantapur and 0.64 at Palem respectively (Fig.16 a&b).

Table 5. Simulated and observed yields of Sorghum crop at Anantapur

Date of sowing	Observed yield	Simulated yield	Error % = {(simulated – observed) / observed} x 100
1-Aug-79 (CSH-6)	1330.0	1602.4	20.5
13-Aug-8 (CSH-6)	642.0	725.7	13.0
25-Jun-81 (CSH-5)	2606.0	1940.2	-25.5
27-Jun-82 (CSH-6)	906.0	1120.5	23.7
17-Jun-83 (CSH-6)	570.0	504.0	-11.6
15-Jul-84 (CSH-6)	276.0	324.6	17.6
26-Jul-85 (CSH-6)	1057.0	1298.0	22.8
Average	1055.3	914.6	8.6

Table 6. Simulated and observed yields of Sorghum crop at Palem

Date of sowing	Observed yield	Simulated yield	Error % = {(simulated – observed) / observed} x 100
24-June-95 (CSV-15)	3062.0	3400.8	11.1
24-June-95 (CSV-13)	3012.0	3400.8	12.9
30-June-97 (CSH-6)	3393.0	3991.6	17.6
30-June-97 (CSH-9)	3714.0	3991.6	7.5
30-June-97 (CSH-14)	3407.0	3991.6	17.2
01-July-97 (CSH-9)	3262.0	3697.1	13.3
29-June-98 (CSH-6)	3457.0	3599.8	4.1
01-July-00 (CSV-13)	3333.0	3697.1	10.9
Average	3330.0	3721.3	11.8

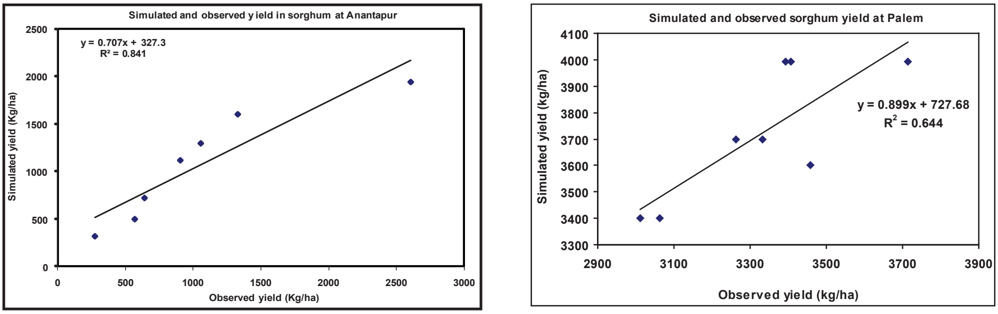


Fig. 16.a&b. simulated and observed yields of Sorghum crop at Anantapur and Palem

Climate change Impact studies

After the validation of the model the crop was subjected to the climate change by values under different dates of sowing (DOS) imposing the 2020, 2050 and 2080 Had CM3 scenarios generated by the model on different dates of sowings and different levels of CO_2 at Anantapur and Palem. The results showed that an average decrease in sorghum yield under climate change scenarios are in the order of 8%, 18% and 30% at Anantapur (Fig. 17). and 2.2, 5.1 and 9.7% at Palem during the years 2020, 2050 and 2080 respectively (Fig. 18).

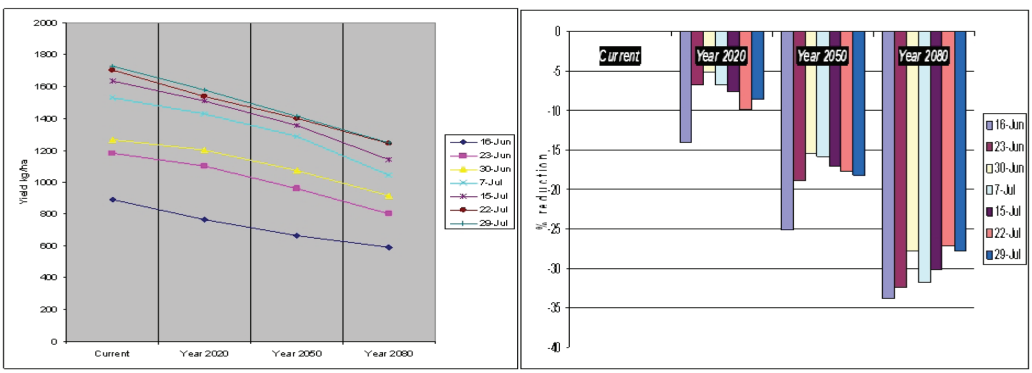


Fig. 17. Impact of climate change on the Yield of Sorghum (kg/ha) at Anantapur

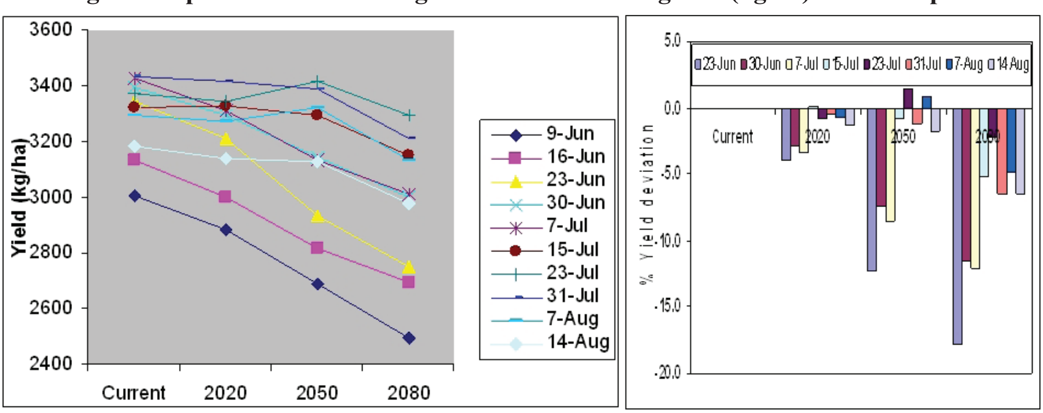


Fig. 18. Impact of climate change on the Yield of Sorghum (kg/ha) at Palem

Objective 2: To evolve operational contingency plans for temperature and rainfall related risks

Under this objective it has been tried to see how the crop behaves under changed dates of sowing as an adaptation strategy in view of delayed season sowing operations due to delayed onset of rainy season. It is observed from the results of the simulations, that to obtain atleast current level of production rates in the year 2020 (Fig. 19). The sowing of the crop to be taken up after 2 weeks to match with the rainfall distribution time during the year 2020. Similarly, for attaining current level production under normal dates of sowing in the year 2020, 2050 and 2080 application of one irrigation at 45 DAS has incorporated and it has improved the yields by 15 to 25 % over the normal yield in 2020, while it is 5 to 10 percent over the normal yield at 2050 and is 5 to 12 % over normal yield of 2050.

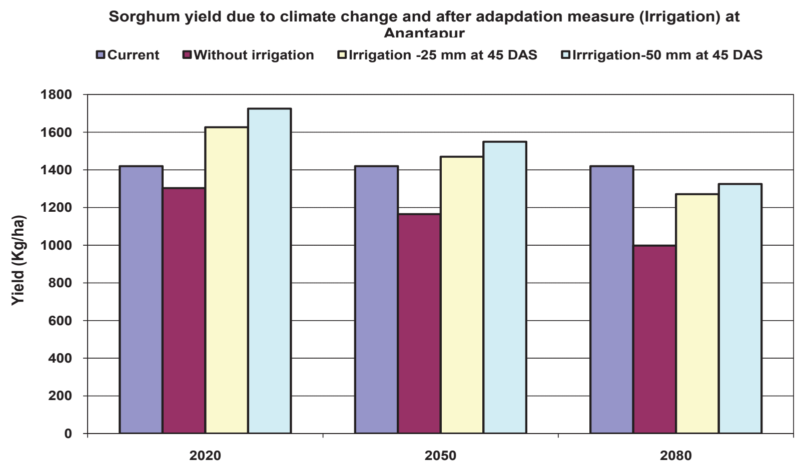


Fig. 19. Percent change in the yields of sorghum after applying the irrigation at 45 DAS at Anantapur and Palem.

Validation of other models (Rice, maize and castor), climate change impact studies and adaptation strategies are in progress.

I. Crop water requirements of Wheat

The crop water requirement (CWR) of wheat crop was computed for the entire wheat growing regions in the 11 states viz. Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan, West Bengal, Maharashtra, Gujarat and Jammu and Kashmir of India using Cropwat 4 Windows Version 4.3. Crop coefficients (Kc) were used to calculate CWR from reference evapotranspiration (ETo) CWR = Kc * ETo. Value of Kc varies with the crop, and its stage. The Kc values were taken from FAO (1998) and also collected from different AICRIPAM centers wherever available.

District wise total water requirement in million cubic meter has been calculated by multiplying the district wise area under wheat crop and total water requirement for the baseline year 1990 and also 2020,2050. Since the district wise weather data for the study area is limited, the data available for some nearby regions are assumed to hold good for the adjoining districts and computations were made accordingly. Finally, the percentage of deviation of water requirement from the baseline year (1990) to total water requirement of 2020 and 2050 were computed.

It is observed from the analysis, that in Jammu & Kashmir, Himachal Pradesh, Punjab and Haryana on an average the increase in water demand over the base year 1990 is 3.5 Percent for the year 2020 and 6.3 percent for the year 2050. Whereas for the states UP, MP, Bihar, Rajasthan and West Bengal the average increase in water demand is 2.6 and 5.7 percent for the years 2020 and 2050 respectively. For Gujarat and Maharashtra states the average increase in water demand is 1.8 and 4.4 percent in the years 2020 and 2050 respectively. Maps showing the variability among the districts for the year 2020 and 2050 for all the above states have been prepared and strategies to meet the additional water requirements are planned (Table 7).

Table 7. Water requirement by the year 2020, 2050 and deviation from base year for wheat crop in different states of India.

State	Total area under Wheat	Water requirements (Million Cubic Meters)			Percent Deviation (2020-1990)	Percen Deviatio (2050-1990)
		1990	2020	2050		
Punjab	34,68,000	12553.6	13002.5	13317.5	3.6	6.1
Haryana	23,16,674	10475.4	10825.3	11157.9	3.3	6.5
HP	3,67,770	1051.1	1089.7	1119.2	3.7	6.5
UP	94,43,104	39717.8	40750.1	41990.4	2.6	5.7
MP	41,88,248	21176.9	21655.3	22200.1	2.3	4.8
Bihar	20,76,727	9046.2	9271.1	9593.9	2.5	6.1
Rajasthan	20,10,241	9923.6	10208	10480	2.9	5.6
West Bengal	3,66,729	1449.5	1479.8	1543.1	2.1	6.5
Maharashtra	9,32,800	5613.8	5718.3	5859.4	1.9	4.4
Gujarat	7,27,400	4603.3	4683.2	4807.1	1.7	4.4
J&K	2,53,023	823.9	851.7	874.5	3.4	6.1

II. Climate Change Studies on Water Availability

- The impact of Climate Change on the water harvesting potential of different regions in Andhra Pradesh was attempted by computing the normal water balance for the years 2020 and 2050 at 21 selected places. Based on Climate Change scenario A_2 a values for these places, PET values were estimated and the projected rainfall values were considered to compute the water surplus by the Thronthwaite and Mather (1955) procedure. The percent deviation for the years 2020 and 2050 are from the baseline year 1990 (Table 8). The highlights of the results are as follows;
- There is no water surplus available in the stations located in the south Telangana, Rayalaseema and in some coastal stations.
- Stations located in the northern Telangana, Krishna, West and East Godavari districts showed water surplus in the baseline year and the values decreased in various percentages in the projected years.
- The reason for declining in the water surplus after baseline year could be attributed to increase in the demand (PET) during these years due to the increase in temperature and only slight variation in the rainfall.

Table 8. Present water surplus in diffrent stations of Andhra Pradesh State

S.NO	STATION NAME	Water Surplus(mm)	Water Surplus(% Deviation from baseline year1990)	
		1990	2020	2050
1	ANANTHAPUR	0	NO CHANGE	NO CHANGE
2	MAHABUBNAGAR	0	NO CHANGE	NO CHANGE
3	KURNOOL	0	NO CHANGE	NO CHANGE
4	AROGYAVARAM	0	NO CHANGE	NO CHANGE
5	BAPATLA	0	NO CHANGE	NO CHANGE
6	CUDDAPAH	0	NO CHANGE	NO CHANGE
7	TIRUPATHI	0	NO CHANGE	NO CHANGE
8	NANDYAL	0	NO CHANGE	NO CHANGE
9	TIRUPATHI	0	NO CHANGE	NO CHANGE
10	MACHILIPATNAM	0	NO CHANGE	NO CHANGE
11	NALGONDA	0	NO CHANGE	NO CHANGE
12	MEDAK	211.9	-6.3	-14.6
13	KARIMNAGAR	158.2	-6.8	-10.2
14	ADILABAD	217.3	-9.0	-15.4
15	NIZAMABAD	228.4	-5.2	-13.2
16	NARSAPUR	98.6	-13.6	-41.0
17	KALINGAPATNAM	74.1	-14.2	-42.9
18	KHAMMAM	30.3	-41.9	-97.0
19	VISAKHAPATNAM	21.2	-49.1	-100.0
20	VIJAYAWADA	10.4	-100.0	-100.0
21	AMARAVATHI	24.8	-45.6	-100.0

III. Decadal shifts in monthly rainfall and annual drought pattern in different agro-climatic zones of Andhra Pradesh

The decadal monthly averages of 23 stations spread over seven agro-climatic zones of Andhra Pradesh revealed that, there is a significant shifts in monthly rainfall pattern during main crop growing Kharif season from June to October. During the months of June and July there is an increased rainfall activity in all agro-climatic zones except North and South Telangana zones. Mostly decreasing or no trend was observed in August month except high altitude zone. This is cause of concern that the decrease in rainfall during August may affect important stage anthesis and flowering of major kharif crops. In the case of September month upward trend was noticed in four agro-climatic zones and same trend was observed in the month of October except in North Telangana zone where there is no trend in rainfall. In the case of annual drought pattern the highest (75%) and lowest (35%) percentage of occurrence of droughts are noticed in North Telangana zone during the decade of 1971-1980 and 1981-1990 respectively. 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 Southern and Scarce rainfall zones. Severe drought was not noticed during the last three decades in North Telangana and High Altitude zones. This condition is welcoming one especially in scarce rainfall zone both moderate and severe drought is in downward trend.

IV. Shifts in Moisture regime at selected locations of India

Methodology

Daily rainfall and actual evaporation data of 24 AICRPAM stations spread over the country formed the base material for this study. The duration of data ranges from 13 years to 36 years among the stations. The potential evapotranspiration values were calculated by standard procedures (FAO Irrigation and drainage paper, No. 24). Weekly moisture Index (Im) through water balance approach was calculated based on the method followed by Thronthwaite and Mather during (1955). The baseline climate type and available water holding capacity of soil for each station has been collected from NBSS publication. (Mandal et.al., 1999). Selection of stations under different climate types as shown in the table below (Table 9).

Table 9. Normal climatic type of selected stations

Climatic type (Symbol)	Stations
Per-humid (A)	Dapoli, Jorhat and Thrissur
Humid (B4)	Mohanpur, Palampur
Humid (B3)	Rani chauri
Humid (B1)	Samastipur
Moist Sub humid (C2)	Bhubhaneswar, Rakh Dhiaser
Dry Sub humid (C1)	Jabalpur, Raipur
Semi-arid (D)	Akola, Anand, Bangalore, Bijapur, Faizabad, Kanpur, Kovilpatti, Ludhiana, Parbhani, Udaipur
Arid (E)	Anantapur, Solapur and Hisar

Per humid stations

Three stations viz., Dapoli, Jorhat and Thrissur fall under perhumid climatic type. Among these three stations, climate at Dapoli and Jorhat was stable and fluctuated occasionally towards humid type. While, moisture regime of Thrissur station was shifted more towards drier side i.e. humid climatic types (B4, B3, B2 and B1) from its normal per humid climatic type.

Humid stations

Mohanpur and Palampur stations are falling under B4 type, while Ranichauri and Samastipur fall under B3 and B1 type of climate under B1 type in the humid climate. Majority of the years Mohanpur, Palampur and Ranichauri stations are veering towards perhumid type. Where as, Samastipur showed a shifts towards subhumid & semi-arid type.

Moist sub humid stations

Bhubaneswar experienced climate shifts majority of times towards humid climates secondly towards semi arid type besides its native climate. While, Rakh Dhiansar station besides its normal climate type, majority of the times it shifted towards semiarid type

Dry sub humid stations

Jabalpur station encountered shifts towards moist subhumid and humid types where as Raipur experienced shifts in climate majority of the times towards Semi-arid climate.

Semi-arid Stations

Peculiar type of climatic shifts was noticed in semi-arid climatic type stations. Among the semi-arid stations Kovilpatti and Bijapur have showed a shifting towards dry climates i.e, arid climatic type. From this it is evident that these two stations are more vulnerable to drought prone. It is noticed that Faizabad climate is shifting towards wetter climatic types like, dry & moist subhumid. However, Udaipur and Akola experiencing major shift towards arid climatic type. Of the remaining five stations, three stations viz., Kanpur, Bangalore and Ludhiana experienced shift towards dry sub humid from semi-arid. Anand and Parbhani stations experienced almost equal shifts between dry sub humid and arid climatic types.

Arid stations

Climate type of arid stations (Anantapur, Hisar and Solapur) fluctuated only towards semi-arid climate type. Among these stations, Anantapur and Hisar are more stable in their normal climatic type than Solapur, where more fluctuation was seen towards semi-arid climatic type.

V. TEMPERATURE TRENDS OVER INDIA

Material and methods

Annual mean maximum, minimum and average temperature data of 47 stations spread across the India was collected, checked for quality for this study (Table 10). Five zones viz., northern, western, eastern, southern and central have been created and these 47 stations were put under respective zones as per IMD guidance. (Northern zone – 5 stations; Eastern zone – 7 stations; Western zone – 14 stations; South zone – 12 stations and Central zone – 9 stations). Time series analysis and statistical significance of trends in temperature data was carried out using Mann-Kendall test statistics (Libiseller and Grimall, 2002).

Table 10. List of stations taken for study

Name of the zone	No. of stations	Station names
North zone	5	Bareilly, Bahraich, Jhansi, New Delhi, Varanasi
East zone	7	Balasore, Daltgunj, Guwahati, Hazaribagh, Kolkata, Krishna nagar, Midnapur
West zone	14	Ahmedabad, Barmer, Baroda, Deesa, Jaipur, Jalagaon, Jodhpur, Kota, Miraj, Pune, Rajkot, Solapur, Surat, Veraval
South zone	12	Anantapur, Arogyawaram, Gulburga, Hanamakonda, Hyderabad, Kalingapatnam, Khammam, Kurnool, Madurai, Mahabubnagar, Mysore, Vizag
Central zone	9	Akola, Ambikapur, Bhopal, Hosangabad, Indore, Jabalpur, Jagdalpur, Nagpur, Seoni

Salient findings

Maximum temperature trends

Increasing trend was noticed in 9 out of 12 stations in south zone followed by central (67%), east (60%) and west zone (57%). In north India only 20 per cent of stations were showing increasing as well as declining trend (Table 2a). No significant trend was observed in 60 per cent of stations in north zone followed by west zone (43%), central zone (37%), south zone (17%) and east zone (14%).

Minimum temperature trends

Minimum temperature showed increasing trend in 88 per cent of stations in central and east zone followed by north zone (80%), south zone (75%) and least in west zone (57%). Decreasing trend in minimum temperature was seen in 29 per cent of stations in west zone followed by 20 per cent and 8 per cent stations in north and south zone respectively. No trend was noticed in 20 per cent of stations in north zone followed by 17% in south zone, 14% in west and 12% each in east and central zone. Deka and Nath (2008) reported that annual mean minimum temperature showed a net increase in Jorhat region of Assam State during the last decade (1991-2000) when compared to previous two decades (1970-1990). More number of stations in all zones have showed on increased trend in minimum temperature (more than 57%) than maximum temperature. This is cause of concern in agriculture, as increased night temperature will accelerate the respiration rate, and hasten the maturity, which in turn reduce crop yields. All regions of India especially east and central zones showing increased trend in minimum temperature.

Average temperature trends

In the case of average temperature trends, all zones followed the same pattern as in the case of minimum temperature except in north zone where 40 per cent of stations have shown increasing trend (Fig. 20). Decreasing trend in average temperature was noticed in 21 per cent of stations in west zone followed by 20 per cent in north zone, 14 per cent in east zone and 8 per cent in south zone. No trend in average temperature was seen in 40 per cent of stations in north zone followed by west (21%), south (17%), east (14%) and central (12%).

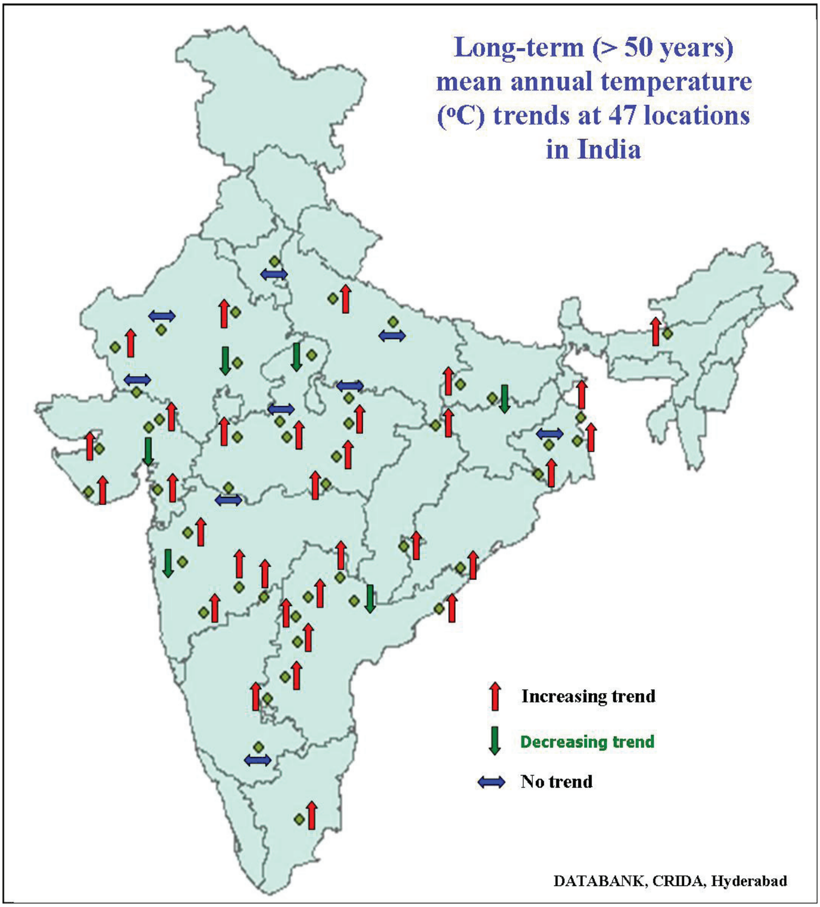


Fig. 20. Trends in Mean temperature over different parts of India

Objective 3 : To assess the response of sorghum varieties to elevated CO_2 levels in terms of growth and seed yield

Two sorghum varieties having contrasting harvest index were chosen to evaluate their response to two elevated CO_2 levels (550ppm & 700ppm) in terms of biomass and seed yield along with ambient CO_2 level (chamber control) and open field control. The sorghum varieties SPV- 1616 and M 35-1 were raised in OTCs at 700ppm, 550ppm and ambient CO_2 levels from sowing to harvest during rabi 2007 and kharif 2008. The crop during Rabi season was maintained stress free by providing irrigation and during kharif season as purely rainfed. During the kharif 2008, the crop received 738.85mm rainfall in well-distributed 24 rainy days.

The biomass accumulation and its partitioning to different plant parts was quantified by destructive sampling at regular intervals. The seed yield and yield components were recorded at final harvest.

Salient findings

Phenology

The days to flag leaf emergence and 50% flowering was early by three days at elevated CO_2 levels in sorghum variety SPV-1616 when compared with ambient control. However, no difference was observed with sorghum variety M 35-1.

Leaf characters

The elevated CO_2 levels resulted higher specific leaf weight in sorghum variety SPV 1616 resulted thicker leaves as compared with ambient level chamber control. However, the SLW response was marginal with sorghum variety M 35-1.

Root characters

The root length, root volume and root dry weight response of two sorghum varieties showed different trend with elevated CO_2 levels. The root volume and dry weight of sorghum variety SPV-1616 improved significantly with increased CO_2 levels whereas under similar conditions there was marginal response was recorded with sorghum variety M 35-1. However, the root length of sorghum variety M 35-1 improved significantly with increased CO_2 levels, which is known for its drought tolerance.

Total biomass

The increased CO_2 levels improved the total biomass of sorghum variety SPV-1616 to the extent of 14% at 700ppm and marginal at 550ppm. The sorghum variety M 35-1 recorded 13% and 8% increment in total biomass at 700ppm and 550ppm CO_2 respectively when compared with ambient chamber control.

Seed yield & fodder

The increase in seed yield due to elevated CO_2 in sorghum variety SPV-1616 was 17% at 700ppm and marginal at 550ppm. However, with sorghum variety M 35-1 the increment in seed yield was

133% and 77% at 700ppm and 550ppm respectively when compared with ambient Ch-control. This bigger yield response of M 35-1 to elevated CO_2 was due to more number of seeds/cob and improved seed weight.

The dry fodder response was similar as seed yield and sorghum variety M 35-1 showed 57% & 45% higher fodder yield at 700ppm & 550ppm CO_2 respectively as compared with ambient Ch-control.

Objective 4: Impact of elevated CO_2 and temperature on insect herbivore and host interactions.

Several experiments were conducted to study the impact of elevated CO_2 on insect pests of castor. Feeding trials using neonate larvae of *S.litura* on castor and groundnut were performed. Groundnut was grown in three conditions, two elevated CO_2 concentrations 700±25, 550±25 ppm in OTCs and ambient CO_2 (350±25ppm) in the open outside the OTC treatments.

Adaptation of insect pests under elevated CO_2 conditions:

Spodoptera litura on groundnut through four successive generations:

The growth, development and consumption of four successive generations of *Spodoptera litura* reared on ground nut foliage grown elevated CO_2 (elevated and ambient) in open top chambers were examined. Changes in the quality of the groundnut foliage effected the growth, development and food utililsation of *Spodoptera litura*. Decrease in nitrogen, water and increased carbon and C:N ratio was noticed. Significantly longer larval life span for third and fourth generations, lower pupal weight for all generations was observed under elevated CO_2 conditions. The fecundity (egg laying capacity) was also decreased for third and fourth generations. The consumption, frass per larva and relative consumption rate and relative growth rate were also significantly varied across generations and CO_2 conditions. The results indicate that CO_2 levels adversely affect the quality of foliage and increased the Relative Consumption Rate of larvae for longer period on groundnut to produce less fecund *S.litura* through generations. Suggesting the net damage by *S.litura* on groundnut will be less under elevated CO_2 atmosphere. The increased consumption is offset by slower development and reduced fecundity. The results are to be revalidated for their conformity.

Relationship of larval and biochemical parameters:

The data on two larval parameters i.e., larval weight and weight of foliage consumed by larva were plotted against each of biochemical constituents (carbon, nitrogen, C:N ratio and TAE - Tanic Acid Equivalents) of each of the foliage obtained from each treatment (on x axis) which was used for feeding trials. It can be seen that consumption and larval weights were positively related with carbon, TAE and C:N ratio and negatively with nitrogen content of leaves.

Multiple regression equations were estimated between larval weights and weight of foliage consumed by both the pests as dependent variable and biochemical parameters as independent variables. The weights of larvae and weight of foliage consumed by both the pests were negatively and significantly influenced by nitrogen content of foliage. The effect of carbon and TAE was not consistent. It is also observed that the effect of nitrogen content is relatively more compared to other two variables as is evident from the higher beta coefficients (0.369-0.684) for nitrogen. This variable together accounted for about 78 – 88 per cent of variation in the larval parameters.

The sequential sum of squares (Table 11) associated with each of the independent variables indicated that nitrogen (0.025-4.744) had a relatively more contribution to the explained variation in the dependent variable. When these results are seen together with the regression coefficients, it becomes evident that nitrogen is more important in determining consumption and weight gain of the larvae. Nitrogen was found to contribute to 75 to 96 per cent of the explained variation. The contribution of carbon was found to be ranging between 3-20 per cent and that of TAE between 0-2.9.

Table 11. Sequential sum of squares and percentage contribution of biochemical parameters to explained variation in larval parameters.

Variable	***Spodoptera litura* on castor**			
	Weight consumed		**Larval weight**	
	Seq. sum squrs	**%**	**Seq. sum squrs**	**%**
Nitrogen	0.244 (86.76)	75.1	0.041 (50.46)	89.1
Carbon	0.077 (27.38)	23.7	0.004 (4.927)	8.7
TAE	0.004 (1.42)	1.2	0.001 (1.23)	2.2
Reg SS	0.325	100	0.046	100

Figures in parentheses are F values

CENTRAL PLANTATION CROP RESEARCH INSTITUTE
KASARAGOD

Objective 1: Study the effect of elevated temperature and CO_2 on response of coconut, arecanut and cocoa seedlings.

Seedlings of coconut (2 hybrids and 3 cultivars), arecanut (5 cultivars) and cocoa (3 hybrids and 4 cultivars) are grown in Open Top Chamber facility with SCADA controlled pumping and monitoring of CO_2 to set level of 550 and 700 ppm and hot air for elevated temperature (+2°C). These seedlings are exposed to above mentioned conditions for past 2 and half years. Several morphological, anatomical, physiological and biochemical parameters were recorded at 4 monthly interval. Some of the mean results were presented in (Table 12).

Table 12. Influence of elevated temperature and CO_2 on anatomical, physiological and biochemical parameters of coconut arecanut and cocoa seedlings.

Parameter	% change from chamber control		
	Temp. (+2 °C)	CO_2 (550 ppm)	CO_2 (700 ppm)
Coconut			
Specific leaf weight	3.6	28.5	2.9
Net photosynthetic rate	-15.8	21.0	85.6
Stomatal conductance	-20.7	-53.3	-25.9
WUE	1.6	124.7	81.2
Leaf water potential	-54.4	11.6	2.3
Chlorophyll a/b ratio	1.9	7.7	1.4
Stomata density	-5.9	-10.7	-14.0
Lower cuticular thickness	16.7	23.5	26.0
Phenols concentration in leaf	-28.5	-2.1	-2.1
Proline in leaf tissue	5.4	121.7	97.1
Total soluble sugars in leaf tissue	-29.7	20.4	41.4
Reducing sugars in leaf tissue	-44.7	29.9	58.0
Amino acids in leaf tissue	5.3	26.4	109.6
Starch in leaf tissue	-10.4	428.2	366.1
SOD activity	67.4	17.4	11.3
PPO activity	-67.7	-80.6	-77.4
Nitrogen in shoot tissue	-15.0	6.0	24.6
Nitrogen in root tissue	-7.2	31.9	13.0
CN ratio shoot	17.4	-6.5	-20.1
CN ratio root	8.2	-24.5	-11.0

Arecanut			
Total dry matter	-8.6	8.4	22.1
SLW	-33.6	-44.0	-38.1
Net photosynthetic rate	13.4	15.0	109.1
Leaf water potential	-10.6	24.6	10.0
Chl a/b ratio	-27.8	17.6	10.2
Leaf let thickness	-0.5	10.9	12.9
Amino acids in leaf tissue	-24.8	95.6	12.9
Total soluble sugars in leaf tissue	49.3	17.6	7.7
Starch in leaf tissue	54.8	154.5	86.3
Phenols in leaf tissue	25.4	20.2	0.4
Nitrogen in shoot tissue	4.4	6.8	7.3
Cocoa			
Root/shoot ratio	2.5	-12.0	-11.5
Total dry matter	-31.5	10.4	33.5
Number of roots	-48.3	-21.0	-15.9
Net photosynthetic rate	15.7	73.9	97.6
WUE	-3.8	20.7	60.4
Leaf water potential	-6.2	12.5	26.6
Chl a/b ratio	3.9	2.8	10.6
Total chlorophyll	25.1	16.1	35.7
SLW	-2.2	7.5	4.3
Leaf let thickness	-3.5	10.7	12.9
Total soluble sugars in leaf tissue	-3.7	-13.8	-13.6
Starch in leaf tissue	37.3	154.5	78.4
Phenols in leaf tissue	-4.0	-11.2	-8.7

Results indicated that the elevated CO_2 increased net photosynthetic rates, TDM in coconut, arecanut and cocoa. Reduced stomatal conductance led to increased water use efficiency in elevated CO_2 conditions in all three crops. Reduction in stomatal density and increase in cuticle thickness due to elevated CO_2 also contributed for this trend. Elevated CO_2 also increased chlorophyll a/b ratio, proline, soluble sugars, reducing sugars, amino acids and starch indicating that elevated CO_2 possibly better equip plants for osmotic adjustment in changed scenario as indicated from maintenance of higher leaf water potential. However, slight reduction in poly phenols may predispose coconut and cocoa plants for pest and disease incidence in elevated CO_2 conditions. Results also indicated that the activity of scavenging enzyme, super oxide dismutase is also high in elevated CO_2 conditions. Specific leaf weight increased in coconut and cocoa while in arecanut it decreased due to elevated CO_2.

Elevated temperature reduced net photosynthetic rates in coconut but increased that of arecanut and cocoa. However, the TDM was slightly decreased in all three crops due to elevated temperatures. The effects of elevated temperature on parameters like SLW, WUE, LWP, chlorophyll a/b ratio, stomatal density, etc. are similar as that of elevated CO_2 in coconut. However, elevated temperature reduced concentrations of soluble sugars, reducing sugars, starch in leaf tissue and nitrogen in shoot and root tissue; on the other hand it increased C/N ratio in shoot and root tissue. In contrast to coconut, arecanut SLW, chlorophyll a/b ratio, concentration of amino acids in leaf tissue decreased while concentration of soluble sugars, phenols, starch and nitrogen increased due to elevated temperature. In cocoa, root/shoot ratio, chl. a/b ratio, concentration of total chl. and starch increased due to elevated temperature but WUE, LWP, SLW, leaf thickness and concentration of phenols are reduced.

Objective 2: Study the suitability of measures of adaptation in coconut plantations to climate change in different agro-climatic zones using simulation model.

Based on the simulation studies, earlier it was reported that the coconut yields are likely to increase in Kerala, parts of Tamil Nadu and parts of Karnataka due to climate change. However, yield is projected to reduce in Andhra Pradesh (mostly irrigated area) and rain fed areas of other states. The field studies conducted indicated that soil moisture conservation is one of the potential and important adaptation strategies to reduce the climate change impacts particularly in water scarce/limited conditions (Table 13).

Table 13. Percent change in number of nuts/palm/year over control palms with soil moisture conservation treatments and irrigation at different agro-climatic centers.

Agro-climatic zone and treatment		Percent change in number of nuts/palm/year over control
Hot semi arid (South Karnataka)	SMC treated	38.18
	Irrigated	-25.21
Western Ghats – hot sub-humid per-humid	SMC treated	17.74
	Irrigated	-1.09
Eastern coastal plains – hot sub humid (TN)	SMC treated	74.51
	Irrigated	12.93
Western coastal area - hot sub-humid per-humid (Maharastra)	SMC treated	19.23
	Irrigated	-15.18
Eastern coastal plains – hot sub humid (Andhra Pradesh)	SMC treated	10.48
	Irrigated	10.00

*SMC: Soil moisture conservation

Using the results obtained from field experiments, the simulation studies on adaptation strategies will be carried out for different agro-climatic zones for reducing the negative impacts in zones where climate change is adversely affecting; and for enhancing the positive effects in zones where climate change is benefiting the coconut plantations.

Objective 3: Study the impact of elevated temperatures on quality of harvested products (cocoa beans, coconut copra and oil and arecanut).

Influence of storage temperature on keeping quality of copra and oil was studied in the context of projected increase in temperature due to climate change. Copra was stored for six months and oil was stored for eight months at several temperatures in the range of 22 to 45°C. Copra quality parameters such as oil, protein starch, carbohydrate and reducing sugars; oil quality parameters such as free fatty acids, acid value, peroxide value were estimated at two monthly interval.

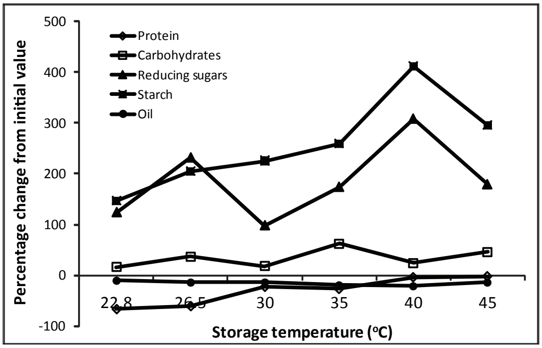


Fig. 21. Change in copra quality after six months of storage at different temperatures

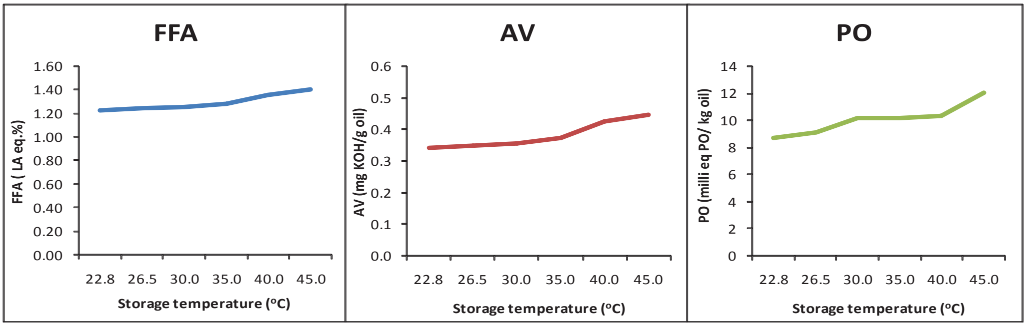


Fig. 22. Mean values of free fatty acids (FFA); acid value (AV) and peroxide value (PO) in oil stored at different temperatures.

Results indicated that increase in storage temperature from 22 to 45 °C reduced oil percentage while it increased starch, carbohydrates and reducing sugars in copra. Apart from this, during storage, concentration of reducing sugars, starch and carbohydrates increased while oil and protein reduced (Fig. 21).

Similarly, increase in storage temperature reduced the shelf life of coconut oil as indicated by increase in free fatty acids, acid value and peroxide value (Fig. 22)

It can be concluded from the results that climate change will alter the quality of copra and coconut oil during storage and the shelf life of copra and coconut oil is likely to reduce if the current storage practices are continued.

Objective 4: Study the carbon sequestration potential and stocks of coconut systems using simulation model.

The carbon sequestration potential of coconut plantations was assessed using real time estimates and Info Crop-Coconut simulation models. The outputs were up-scaled to state level. Such estimations were carried out for four major coconut growing states viz., Kerala, Tamil Nadu, Karnataka and Andhra Pradesh, which have about 90% of all India coconut area and production (Fig. 23).

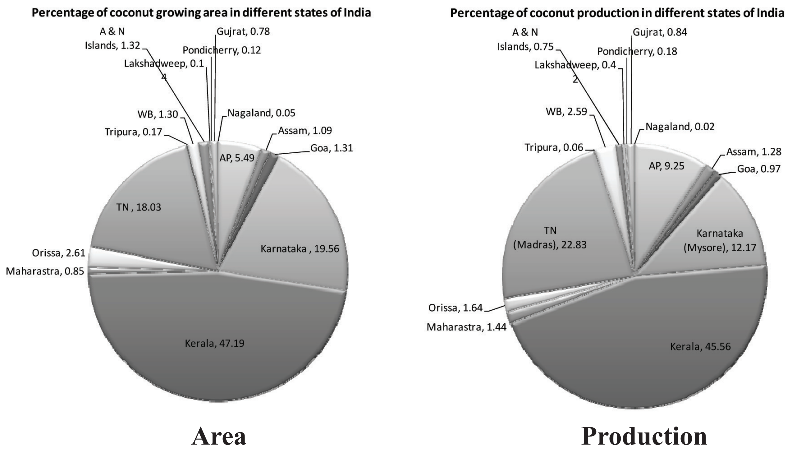


Fig. 23. Percentage of area and production of coconut in different states of India

Simulation results indicated that the carbon sequestered and stored in stem in coconut plantations in four states viz., Kerala, Karnataka, Tamil Nadu and Andhra Pradesh is to the tune of 0.732 million tonnes of carbon every year (Table 14).

Table 14. Carbon sequestration in coconut plantations in India

State	Carbon sequestered in to stem (million T C/year)	CO_2 sequestered into stem (million T CO_2/year)
Kerala	0.442	1.621
Tamil Nadu	0.141	0.518
Karnataka,	0.107	0.392
Andhra Pradesh	0.042	0.154

These suggest that coconut has a vast carbon sequestration potential. These values can dramatically go up if all other aspects of carbon sequestration are taken into consideration. Such analysis is under progress.

INDIAN INSTITUTE OF HORTICULTURAL RESEARCH

BANGALORE

Objective 1: To study the effects of elevated CO_2, temperature, water stress on growth, water use efficiency, quality and yield of tomato and onion.

Impact of Elevated CO_2 on growth and yield of tomato

Response of tomato cv. Ashish to elevated CO_2 (550ppm) was studied in Open Top chambers. Two OTCs were maintained at 550 ppm and two were maintained at ambient level (365ppm) without any external CO_2 supply as chamber control (Ch-control). The CO_2 concentrations were maintained and continuously monitored during experimental period. The observations on shoot dry weight, leaf area and total biomass were recorded at 20, 40, 60, 80, and 100 DAP. For each treatment three plants were sampled in three replications from each chamber. Shoot dry weight increased throughout the crop growth period under elevated CO_2. The shoot dry weight increase at 550 ppm was highest at 125 DAP (144.4 g). LAI was 4.56 and 4.93 at 550 ppm CO_2 compared to chamber control 3.72 and 3.21 at the flowering and fruiting stages, respectively in plants grown at a 365ppm. Elevated CO_2 levels enhanced the total biomass at all growth stages. Total biomass was maximum at 90DAP (496.55 g/Plant) compared to control (346.42 g/plant). The percent increment in total biomass at elevated CO_2 varied from 52 to 81% at different growth stages.

There was an increase in the photosynthetic rate by 10% at the vegetative, 37% at the flowering and 28% during the fruiting stage. Stomatal conductance decreased at all the stages at 550ppm CO_2 compared to ambient CO_2 (365ppm) (Table 15). Transpiration rate also decreased at different stages at 550 ppm CO_2. Per plant yield at elevated CO_2 was 5.54 Kg/Plant compared to plants grown at ambient CO_2 (4.38 Kg/plant). Yield increase was mainly due to increase in the number of fruits per plant at elevated CO_2 (94 fruits/plant) compared to chamber control (76 fruits/plant). A yield increase of 26.5% was observed at elevated CO_2 concentration compared to chamber control. Quality parameters were also studied. There was no increase in the lycopene and carotenoid content at elevated CO_2 compared to chamber control. Antioxidants were higher at elevated CO_2 concentrations (Table 16).

Table 15. Photosynthesis (µmol m^{-2} s^{-1}), Stomatal conductance (mol m^{-2} s^{-1}) and transpiration rate (mol m^{-2} s^{-1}) of tomato at elevated and ambient CO_2.

Growth stage	Photosynthesis	Stomatal Conductance	Transpiration
550 ppm			
Vegetative	17.45	0.45	6.51
Flowering	23.10	0.62	10.25
Fruiting	25.43	1.08	10.57
365 ppm			
Vegetative	15.90	0.55	11.34
Flowering	16.90	0.74	12.05
Fruiting	19.80	1.11	11.40

Table 16. Quality parameters in tomato at elevated and ambient CO_2 condition at peak picking stage.

Parameter	550ppm	OTC 365ppm
Carotenoids (mg of β carotene eqt /100g)	6.18	11.0
Lycopene (mg of lycopene /100g)	2.98	5.61
Total Phenols (mg of gallic acid eqt/100g)	15.989	18.174
Flavonoids (mg of catechin eqt/100g)	8.438	8.775
Antioxidants (mg of AEAC units/100g)		
FRAP	15.558	13.508
DPPH	12.9	2.232
TSS (%)	5.20	5.00

Studies on the effect of flooding on bulb onion growth and bulb yield

A study was conducted to determine the effect of flooding on plant performance and plant yield in onion (cv. Arka Kalyan). Four weeks seedlings were planted in 12” dia. plastic pots. The flooding was imposed at bulb initiation stage (55 DAP) and active bulb growth stage (85 DAP). The flooding was imposed for 7 days period as follows: a) in one group of plant, flooding was imposed once and after 7 days the flooding stress was released; b) in another group of plants, the flooding was maintained for 7 days by adding the water regularly (continuous flooding). The observations on gas exchange parameters were made during the flooding period. The plant samples were collected after 7 days of releasing the flooding stress for determining leaf area production, plant fresh and dry mass, leaf senescence and bulb yield.

There was a reduction of 25.0% and 51.0% in leaf area in the plants where the flooding was imposed once and under the continuous flooding, respectively (Fig. 24). There was 75.0 to 86.0% reduction in leaf photosynthesis, 28.0 to 46.0% in total plant fresh and 26.0 to 47.0% in dry mass production under flooding (Fig. 24). Though there was no substantial difference in shoot fresh and dry mass between control and flooded plants, a considerable reduction was observed in leaf and bulb fresh mass under the flooding and the reduction was more pronounced in continuous flooding plants. The leaf senescence was more (60.0 to 74.3%) in the plants grown under flooding. The highest percentage of leaf senescence was found in the plants where the flooding was imposed continuously (68.0 to 74.0%) than the once (60.0 to 68.0%) at both the bulb initiation (55 DAP) and active bulb growth stage (85 DAP) (Fig. 25). The reduction in the above morpho-physiological parameters resulted in a substantial reduction in bulb yield of onion. The bulb initiation stage was found to be sensitive as the continuous flooding at this stage resulted in maximum reduction in bulb size (27.2%) (Plate1) and bulb yield (48.3%).

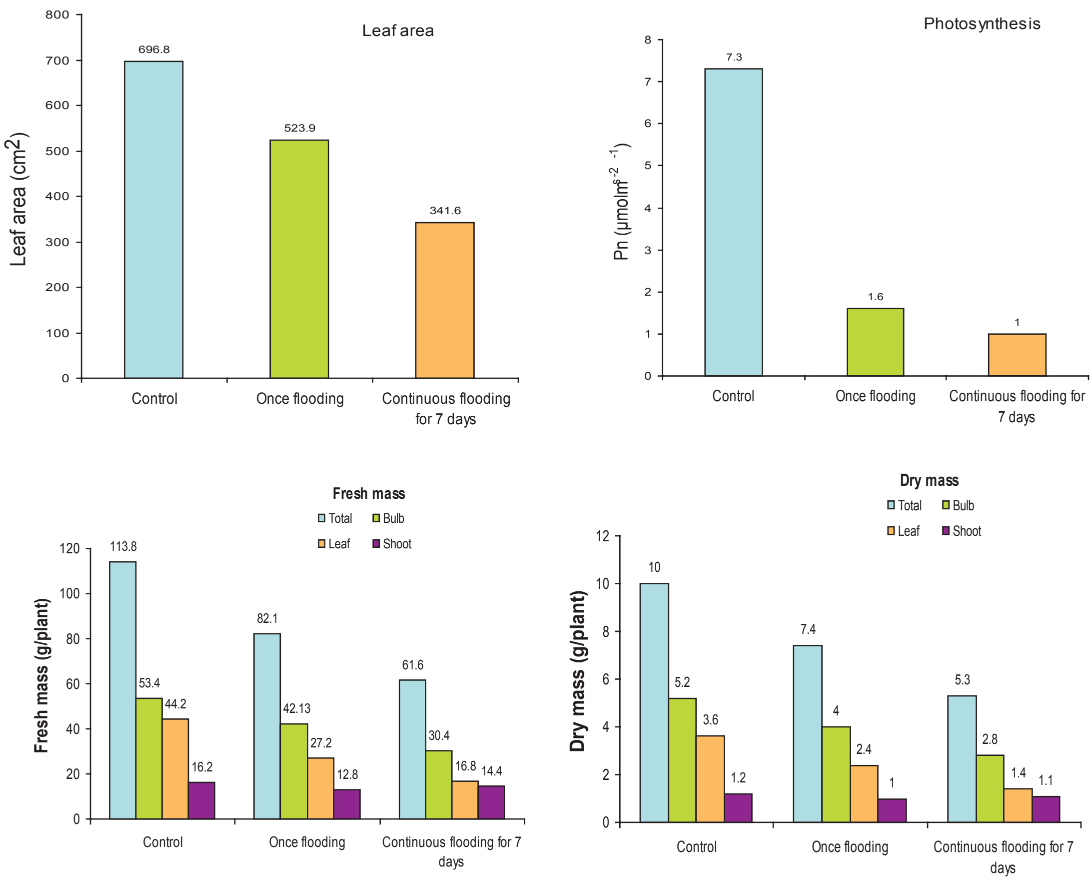


Fig. 24. Effect of flooding on leaf area, photosynthesis, fresh and dry mass accumulation in onion (cv. Arka Kalyan).

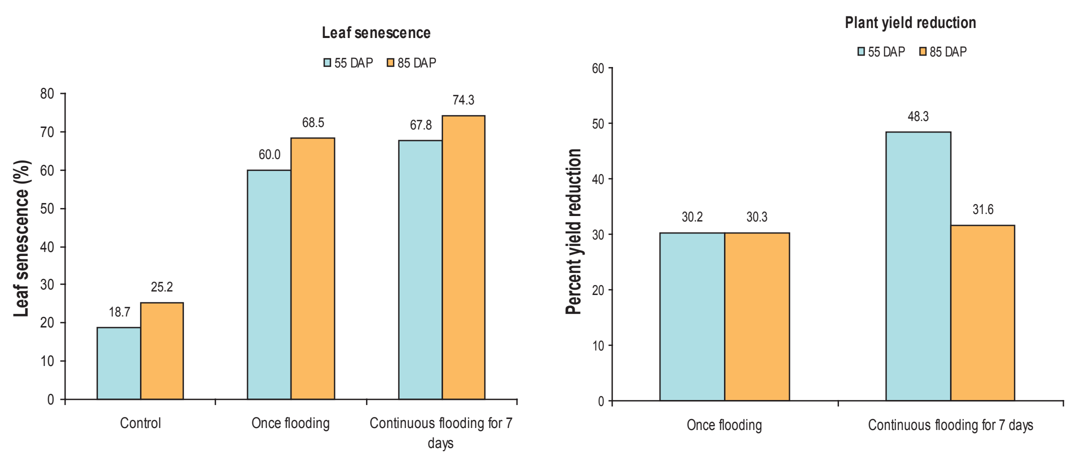


Fig. 25. Leaf senescence and plant yield reduction caused by flooding in onion (cv. Arka Kalyan).

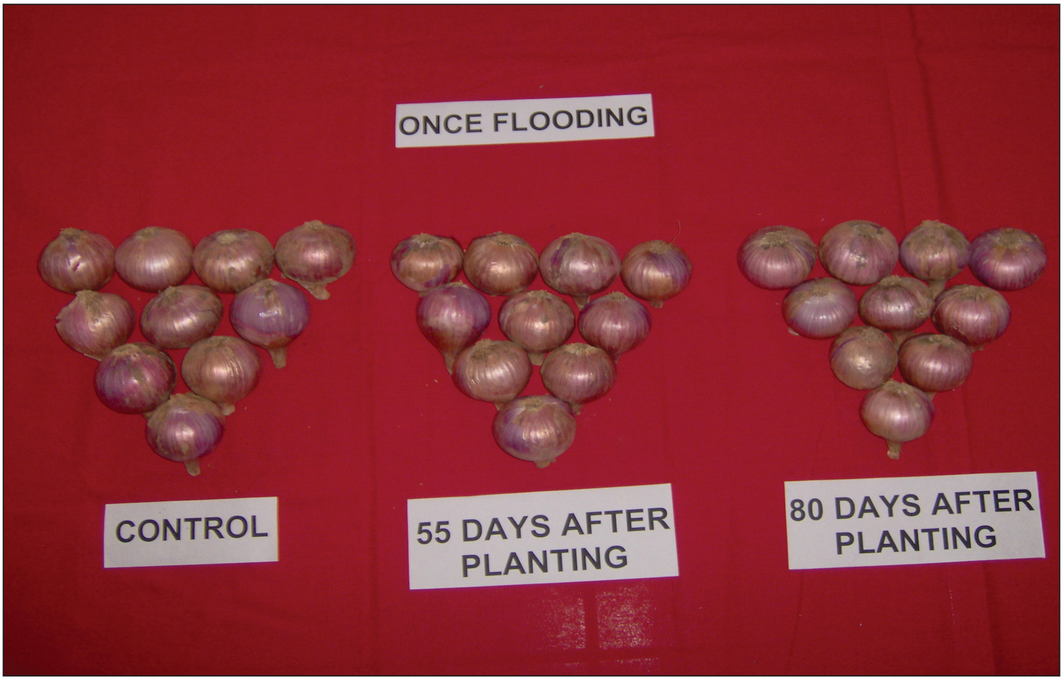


Plate 1. The effect of flooding imposed at bulb initiation stage (55 DAP) and active growth stages (85 DAP) 55 on bulb size.

Objective 2. To correlate prevailing climatic conditions to phenology, crop performance and quality of grape fruits and wine from different grape growing regions.

Studies on phenology and relationship between temperature and quality of wine grapes grown in different regions

The crop duration from pruning to harvest maturity differed between regions for both the wine grape cvs. Shiraz and Cabernet Sauvignon. In Nasik region cv. Shiraz took around 150 to 165 days for crop maturity and cv. Cabernet Sauvignon around 160 to 175 days. In Bangalore region cv. Shiraz took around 165 days and cv. Cabernet Sauvignon around 175-180 days. The days taken for harvest maturity were lowest in Bijapur region, cv. Shiraz took around 140-150 days and cv. Cabernet Sauvignon around 160 days. The fruits samples from different regions were collected and analysed for quality parameters. The relationship between prevailing maximum and minimum temperatures during verasion to harvest maturity and quality parameters were worked out.

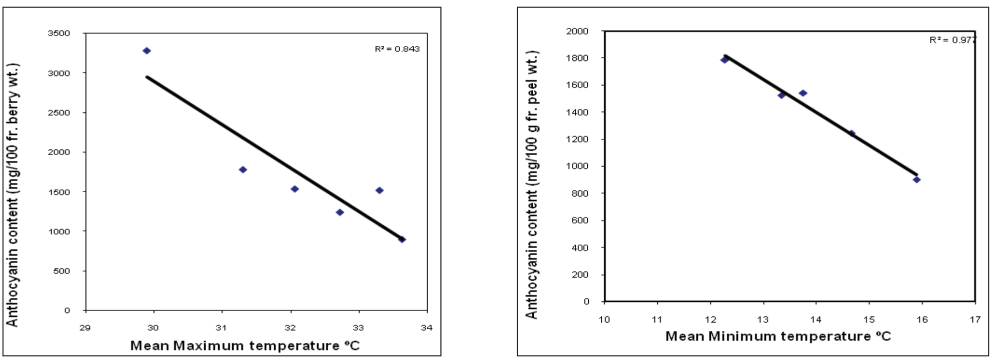


Fig. 26. Relationship between mean maximum and minimum temperature and anthocyanin content in cv. Shiraz.

The relationship of mean maximum and minimum temperatures during veraison to fruit maturity with peel anthocyanin content showed a negative relationship in the cv. Shiraz (Fig. 26). The increase in both maximum and minimum temperatures caused reduction in anthocyanin content at harvest.

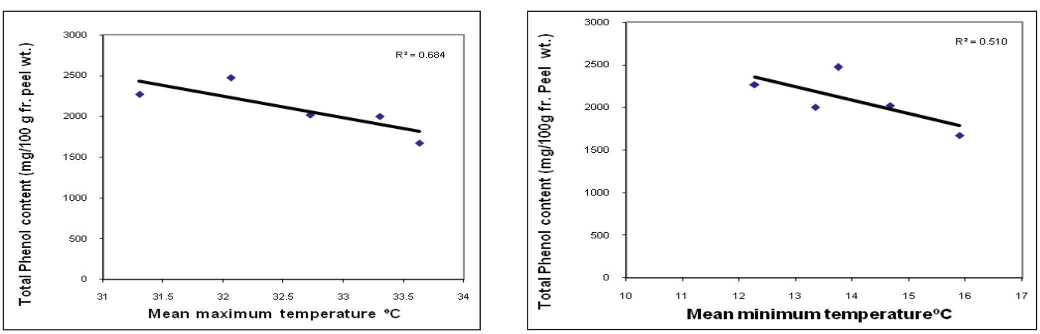


Fig. 27. The relationship between mean maximum and minimum temperatures on peel total phenol content in cv. Shiraz.

The peel total phenol content also showed a negative relationship. The reduction in total phenol content was noticed due to increase in both maximum and minimum temperatures.

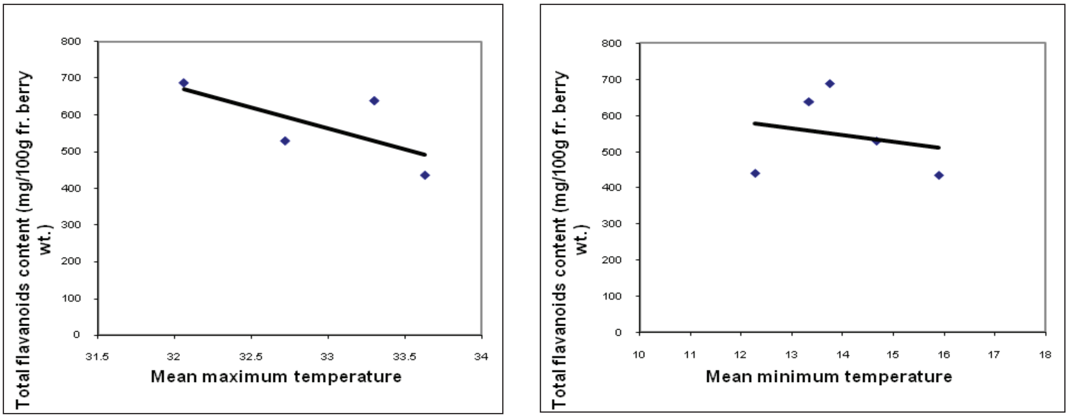


Fig. 28. The relationship between mean maximum and minimum temperature and total flavonoids content

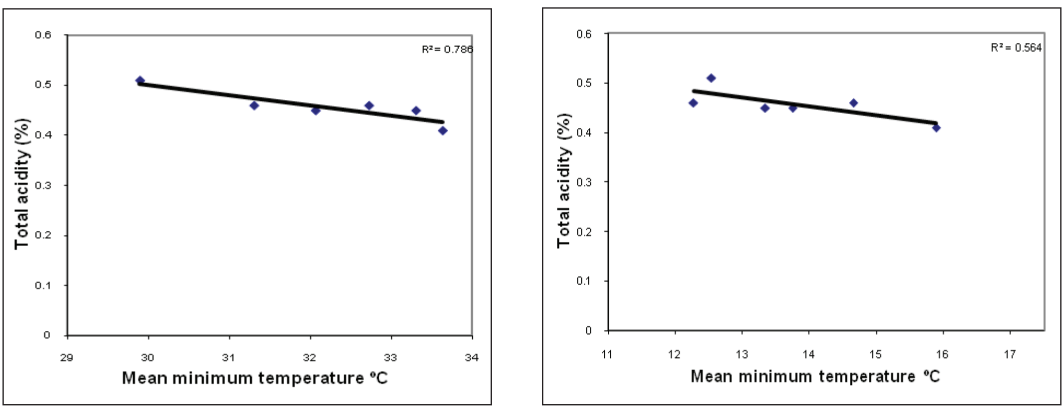


Fig. 29. The relationship between mean maximum (a) minimum (b) and berry juice acidity in cv. Shiraz.

The relationship between temperature and total flavonoids and acidity also showed a negative relationship. The increase in both maximum and minimum temperatures caused the reduction in total flavonoids and acidity. The R^2 values show that the relationship of temperature was stronger with peel anthocyanin content compared to other quality parameters. Indicating that the development of anthocyanin is more influenced by the increases in temperature under climate change conditions.

Objective 3: To assess the impact of climate change on onion and tomato using validated InfoCrop model and working out adaptation strategies and assessing vulnerability of these crops under different agro-climatic regions.

INFOCROP model for onion was further calibrated using the data obtained from field experiments conducted at IIHR, Bangalore and from published literature of the experiments under Bangalore, Dharwad and Delhi conditions. Validation of the model was taken up with the inputs from experiments conducted at different agro-ecological regions and seasons.

Table 17. Validation of the model for different locations

Location	Year/ Season	Date of Transplanting	Days to Bulb initiation		Days to Maturity		Yield t/ha	
			M	O	S	O	S	O
Bangalore	1985 Rabi	15th Nov	50	48	135	140	43	40
Nasik	2000 Rabi	1st Jan	52	50	125	130	22.5	25
Delhi	2000 Rabi	1st Jan	70	75	130	135	37	35
Hyderabad	1994 Rabi	2nd Dec	60	55	122	125	26	25
Dharwad	1999 Kharif	23rd July	50	47	120	125	30	26

S = Simulated, O = Observed

Further validation of the model for nitrogen and irrigation levels under different agro-ecological condition is in progress.

CSK HIMACHAL PRADESH AGRICULTURAL UNIVERSITY
PALAMPUR

Objective 1: To simulate the impacts of different scenarios of climate change on major crops of H.P. and to quantify the suitability of various agronomic measures for adaptation to climate change.

Validation of Crop Model for Soybean Crop

The historical data from AICRIP –Soybean was used to validate the INFOCROP Model. The data from 2004 to 2008 was used. Simulated and Observed days to maturity and yield for soybean crop in Palampur were compared. To asses the impact of elevated carbon dioxide and temperature and rainfall variability, the crop model was run for 20 years from 1989 to 2008. The mean yield and coefficient of variance of 20 years simulated yield were worked out.

Table 18. Simulated and Observed days to maturity for Soybean Crop in Palampur

Sr. No.	Planting date	Simulated	Observed
1	10 June, 2004	140	133
2	20 June, 2004	139	134
3	10 June, 2005	128	118
4	20 June, 2005	135	125
5	10 June, 2006	135	123
6	20 June, 2006	129	119
7	10 June, 2007	138	130
8	20 June, 2007	133	128
9	10 June, 2008	141	133
10	20 June, 2008	134	124

Table 19. Simulated and Observed Yield for Soybean Crop in Palampur

Sr. No	Planting date	Simulated	Observed
1	10 June, 2004	2225	2449
2	20 June, 2004	2528	2325
3	10 June, 2005	2214	2005
4	20 June, 2005	2142	1983
5	10 June, 2006	2200	2041

6	20 June, 2006	2100	1925
7	10 June, 2007	2450	2200
8	20 June, 2007	2267	2083
9	10 June, 2008	1825	1991
10	20 June, 2008	1801	1950

Observed data From AICRIP Kangra

Planting Windows

The simulated results on yield data indicated 10th June sown crop to be the best planting window for soybean followed by 20th June. The recent decade results indicated advantage of 4.7 to 6.1% in yield over the first decade 1989-98. The temperature data also revealed a decrease of 0.2^{0}c in mean temperature where as minimum temperature showed a decrease of 1.6^{o}C in recent decade from 1994-05. On an average 141 days were taken for maturity of 10th June sown crop followed by 20 June 135 days and 30 June sown crop also took 135 days for maturity (Table 20). Under elevated carbon dioxide and temperature conditions early planting on 10th June proved to be the best plating time for soybean.

Impact of elevated carbon dioxide

Elevated levels of carbon dioxide showed an increase in yield of soybean in all the planting windows from June 10 to 30th June. The 50 ppm and 100 ppm elevated levels of carbon dioxide increased yield by 5% and 10.2 percent yield in soybean based on 20 years simulated results under rainfed conditions (Table 21). Compared to control crop took almost equal number of days for maturity in both 50 and 100 ppm elevated carbon dioxide levels with three days delay in maturity in 30th June sown crop.

Impact of elevated temperature

Two levels of temperature 1 and 2^{0}C were tried and model was run for 20 years from 1989 to 08. The simulated yield with 1 and 2^{0}C rises in temperature were compared with control with no change in temperature under rainfed and recommended conditions. The temperature rise of 1and 2^{0}C caused reduction to the tune 1.3 to 3.5 and 4 to 6 percent in all planting windows. The magnitude of decrease was more in 10th June sown crop. The percent decrease increase with further increase in temperature to 2^{0}C (Table 22). One deg rise in temperature caused 1 to 2 days advancement in maturity whereas 2^{0}C rise in temperature advanced the maturity by 3 to 6 days.

Impact of elevated temperature and Carbon dioxide

The temperature rise of 1 and 2^{0}C coupled with 50 ppm elevated carbon dioxide (Table 23) increased the yield in all planting windows. The increase was more in 1^{0}C rise (6.6 to 8.3%) than 2^{0}C (3.0 to 5.0%) rise in both maximum and minimum temperature coupled with 50 ppm higher level of carbon dioxide. The further increase in carbon dioxide levels to 100 ppm (Table 24) from control of 370 ppm with temperature rise of 1 and 2^{0}C showed increase in yield. The magnitude of increase in yield was higher ranging 11 to 13.6 percent in 1^{o}C rise temperature compared to 2^{0}C rise in temperature (7 to 10%). 100 ppm carbon dioxide coupled with temperature rise of 1 and 2^{0}C caused higher increase in yield that 50 ppm with temperature. One degree rise in temperature coupled with 50 ppm higher level of CO_2 advanced the maturity of crop by 2-3 days only whereas 2^{0}C+50`ppm advanced maturity by 4-7 days. Further increase of carbon dioxide to 100 ppm showed similar no of days in advancing the maturity period (Table 25).

Impact of elevated temperature and Carbon dioxide and rainfall

Reduction in rainfall was simulated for 10 years of weather data revealed benefited of decrease in rainfall over existing conditions. 10 percent decrease in rainfall increased the yield by 1 to 1.5 percent, whereas one degree rise in temperature with 420 ppm carbon dioxide and 10 percent reduction in rainfall increased the yield by 8.4 to 12.7.

Table 20. Impact of climate change on planting windows on soybean yield

Planting Window	1989-98		1999-08		Percent Increase / Decrease
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	
10 June	2214.3 (29.5)	141.8 (11.2)	2338.5 (33.0)	140.0 (5.0)	5.60
20 June	2005.6 (35.5)	138.0 (13.7)	2100.3 (39.2)	135.9 (5.2)	4.72
30 June	1566.4 (51.6)	134.8 (15.0)	1663.4 (54.3)	131.0 (6.2)	6.19

Table 21. Impact of elevated CO_2 levels on soybean yield at 1989-08

Planting Window	1989-08						Percent Increase/Decrease	
	Control (370 ppm)		420 ppm		470 ppm			
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	50 ppm	100 ppm
10 June	2276.4 (30.7)	141.0 (8.9)	2391.4 (30.6)	139.6 (8.2)	2508.5 (30.5)	140.5 (8.3)	+ 5.05	+ 10.20
20 June	2052.9 (36.5)	137.0 (6.1)	2155.5 (36.5)	138.0 (10.3)	2260.6 (36.4)	136.9 (10.1)	+ 5.0	+ 10.12
30 June	1614.9 (51.8)	132.5 (8.3)	1699.5 (51.7)	137.4 (11.6)	1778.1 (51.8)	136.4 (11.5)	+ 5.24	+ 10.11

Table 22. Impact of 1⁰C and 2⁰C rise temperature on soybean yield at 1989-08

Planting Window	1989-08						Percent Increase/Decrease	
	Control		1⁰C rise		2⁰C rise			
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	1⁰C rise	2⁰C rise
10 June	2276.4 (30.7)	141.0 (9.2)	2247.3 (29.5)	137.9 (6.0)	2176.4 (31.0)	135.4 (5.5)	- 1.28	- 4.39
20 June	2103.7 (34.9)	137.0 (10.0)	2056.4 (36.6)	135.8 (9.4)	1987.5 (36.7)	132.4 (6.1)	- 2.25	- 5.52
30 June	1674.0 (49.1)	132.4 (11.2)	1615.8 (52.1)	131.4 (9.2)	1573.8 (53.2)	129.1 (7.6)	- 3.48	- 5.99

Table 23. Impact of 1⁰C and 2⁰C rise temperature + 420 ppm on soybean yield at 1989-08

Planting Window	1989-08						Percent Increase/Decrease	
	Control		1⁰C rise+420 ppm		2⁰C rise + 420 ppm			
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	1⁰C rise	2⁰C rise
10 June	2214.3 (29.5)	141.0 (9.2)	2361.1 (29.5)	137.9 (6.0)	2281.7 (30.9)	136.4 (5.7)	+ 6.63	+ 3.04
20 June	2005.6 (35.5)	137.0 (10.0)	2157.6 (36.6)	135.7 (9.3)	2085.3 (36.7)	130.7 (5.9)	+ 7.58	+ 3.97
30 June	1566.4 (51.6)	132.4 (11.2)	1697.0 (52.0)	130.3 (9.0)	1652.5 (53.1)	128.1 (7.5)	+ 8.34	+ 5.50

Table 24. Impact of 1⁰C and 2⁰C rise temperature + 470 ppm on soybean yield at 1989-08

Planting Window	1989-08						Percent Increase/Decrease	
	Control		1⁰C rise + 420 ppm		2⁰C rise + 420 ppm			
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	1⁰C rise	2⁰C rise
10 June	2214.3 (29.5)	141.0 (9.2)	2477.7 (29.7)	137.1 (6.4)	2388.6 (31.1)	135.4 (5.8)	+ 11.89	+ 7.87
20 June	2005.6 (35.5)	137.0 (10.0)	2259.1 (36.7)	134.3 (9.3)	2183.8 (36.7)	129.4 (5.8)	+ 12.64	+ 8.88
30 June	1566.4 (51.6)	132.4 (11.2)	1779.9 (51.8)	130.2 (8.9)	1729.0 (53.1)	129.2 (7.6)	+ 13.63	+ 10.38

Table 25. Impact of rainfall and rainfall+ carbon dioxide +I^{0}C in temperature

Planting windows	Cotrol (370+normal)	370ppm+ (-105Rf)	Percent change	420ppm+1^{0}Cc+ (-105Rf)	Percent change
10 June	2214.3 (29.5)	2245 (15)	1.4	2401 (14)	8.4
20 June	2005.6 (35.5)	2028 (17)	1.1	2229 (15)	11.2
30 June	1566.4 (51.6)	1589 (26)	1.5	1765 (24.6)	12.7

Mustard (Rabi Season)

Methodology

Validation of Crop Model for Mustard Crop

Two field experiment were conducted to generate the crop data for mustard to validate. The field experiments were conducted during 2007 and 2008 during rabi season under four different sowing environment. The mustard crop model was validated for Palampur region and the validated models were used for assessment of climate change impact under different situations. Simulated and Observed days to maturity, days to flowering and yield of mustard crop in Palampur were compared. Results showed that observed days to anthesis for mustard crop at Palampur were 5 days late in observed than that of simulated values. Whereas days to maturity were 6 six days early than that of in simulated. The RMSE values for ten dates compared was 138 kg averaged over all dates from 2004-2008. To asses the impact of elevated carbon dioxide and temperature and rainfall variability, the crop model was run for 20 years from 1989 to 2008. The The mean yield and coefficient of variance (CV) of 20 years simulated yield were worked out (Tables 26-28).

Table 26. Simulated and Observed Days to anthesis for Mustard Crop in Palampur

Sr. No.	Planting date	Simulated	Observed
1	10 October, 2007	48	53
2	20 October, 2007	56	57
3	30 October, 2007	61	66
4	09 November, 2007	62	70
5	10 October, 2008	45	52
6	20 October, 2008	50	56
7	30 October, 2008	54	59
8	09 November, 2008	57	63

RMSE=5.4 Observed yield = 60.8+.971 (Simulated yield)

Table 27. Simulated and Observed days to maturity for Mustard Crop in Palampur.

Sr. No.	Planting date	Simulated	Observed
1	10 October, 2007	157	154
2	20 October, 2007	151	152
3	30 October, 2007	145	153
4	09 November, 2007	134	141
5	10 October, 2008	121	129
6	20 October, 2008	120	125
7	30 October, 2008	120	124
8	09 November, 2008	111	120

Table 28. Simulated and Observed Yield for Mustard Crop in Palampur

RMSE=138.7 Observed yield = 60.8+.971(Simulated yield)

Sr. No.	Planting date	Simulated	Observed
1	10 October, 2007	1757.8	1703.9
2	20 October, 2007	1656.6	1499.1
3	30 October, 2007	1439.3	1227.5
4	09 November, 2007	1143.9	921.7
5	10 October, 2008	1570.6	1518.5
6	20 October, 2008	1408.6	1287.1
7	30 October, 2008	1185.7	1141.4
8	09 November, 2008	947.9	870.4

Comparison of simulated and observed yield of mustard under Palampur Conditions

The simulated yield and observed yield was validated and RMSE was worked out indicated 138.7 kg per hectare average deviation from the observed yield.

Planting Windows under rainfed and irrigated levels

The mustard crop under recommended package and practices were simulated in rainfed, two, three, four and six irrigations conditions. The simulations were done for 1989-08 for ten years. The results revealed that 09 November to be the best planting window but this planting shifted to early date to 20 October under two and three irrigations conditions. Under the four and six irrigations levels, 10 October was the best planting date for mustard under sub humid sub temperate conditions of H.P. (Tables 29-32). Similar trends were observed when temperature and carbon dioxide were increased.

Impact of elevated levels of temperature on Mustard yield rainfed and irrigated levels

Under rainfed and two irrigations conditions 1^0C rise in temperature caused reduction in yield in 10 to 09 November sown crop. Further increase in temperature of 2^0C caused more reduction in yield under all dates of sowing. Four and six irrigations conditions were benefited with 1-2^0C rise temperature in all the sowing windows (Tables 29-32).

Impact of elevated levels of carbon dioxide on Mustard yield rainfed and irrigated levels

Elevated levels of carbon dioxide 420 and 470 ppm were simulated for 1989-08 under rainfed, two, three, four and six irrigations conditions. The higher levels of carbon dioxide showed in general decrease in yield all dates of sowing and irrigated conditions. However, the results simulated were inconsistent. The magnitude of increase in yield was higher under three to six irrigation conditions. The yield showed increase with higher levels of CO_2 but decrease was observed when compared with control.

Impact of elevated levels of temperature + Elevated carbon dioxide on Mustard yield rainfed and irrigated levels

Under rainfed and two irrigations conditions yield of mustard decreased with rise in 1^0C and 2^0C temperature over different dates of sowing. The four and six irrigations levels simulated yield over 1989-08 showed Increase in yield in all planting windows with 1and 2^0 C rise in temperature + 50ppm carbon dioxide. The higher level of carbon dioxide 470 ppm plus 1^0C and 2^0C rise in temperature cause reduction in yield in early sowing upto 20 Oct but later dates were benefited.

Impact of rainfall reductions and temperature rise in mustard yield under rainfed and irrigated levels.

The rainfall reduction plus one degree rise in temperature in rabi season caused decrease in yield in all the planting windows when compared with normal conditions based on last one decade data. The magnitude of decrease in yield due to rain fall reduction and increased temperature and co2 was more in early sowing than delayed sowing of crop.

Table 29. Impact of Increased temperature on Mustard yield under rainfed condition

Sowing dates	Control	1^0C rise	% change	2^0C rise	% change
10 Oct.	725 (97.0)	589 (96.0)	-18.8	491 (107.0)	-32.3
20 Oct.	979 (77.0)	974 (84.0)	-0.5	656.5 (93.0)	-32.9
30 Oct.	1120 (70.0)	1211.5 (61.0)	-1.7	988 (73.0)	-11.8
09 Nov.	1284 (45.0)	1247 (51.0)	-2.9	1080 (62.0)	-15.9

Table 30. Impact of Increased temperature on Mustard yield under 2 irrigation levels

Sowing dates	Control	1^0C rise	% change	2^0C rise	% change
10 Oct.	1247 (57.0)	1115 (64.0)	-10.6	1017 (66.0)	-18.4
20 Oct.	2498 (10.0)	1646.6 (53.0)	-34.1	1262 (70.0)	-49.5
30 Oct.	1701 (32.0)	1536 (24.0)	-9.7	1527 (47.0)	-10.2
09 Nov.	1642.8 (24.0)	1565 (31.0)	-4.7	1523 (33.0)	-7.3

Table 31. Impact of elevated CO_2 levels (420ppm) on Mustard yield under Rainfed

Sowing dates	Control	420ppm	% change	470 ppm	% change
10 Oct.	725 (97.0)	656 (104.0)	-9.5	703 (96.0)	-3.0
20 Oct.	979 (77.0)	615 (81.0)	-37.2	951 (81.0)	-2.9
30 Oct.	1120 (70.0)	877 (85.0)	-21.7	1112 (73.0)	-0.7
09 Nov.	1284 (45.0)	1261 (44.0)	-1.8	1177 (54.0)	-8.3

Table 32. Impact of elevated carbon dioxide levels (470 ppm) & 1^0C increase in temperature on Mustard yield under Rainfed conditions.

Sowing dates	Control	1^0C rise	% change	2^0C rise	% change
10 Oct.	725 (97.0)	536	-26.1	614	-15.3
20 Oct.	979 (77.0)	775	-20.8	833	-14.9
30 Oct.	1120 (70.0)	1053	-5.9	1098	-2.0
09 Nov.	1284 (45.0)	1134	-11.7	1207	-6.0

Table 33. Impact of elevated carbon dioxide (470ppm) + 1^0C rise in temperature under Rainfed conditions.

Sowingdates	Control	1^0C rise	% change	2^0C rise	% change
10 Oct.	725 (97.0)	556 (98.0)	- 23.3	639 (98.0)	- 11.9
20 Oct.	979 (77.0)	858 (94.0)	- 12.4	879 (82.0)	- 10.2
30 Oct.	1120 (70.0)	1076 (68.0)	- 4.0	1028 (65.0)	- 8.2
09 Nov.	1284 (45.0)	1148 (60.0)	- 10.6	1123 (53.0)	- 12.5

Objective 2 : Socio-economic surveys on honey bee's habitat at different elevation zone H.P. to asses climate change and Monitoring the phenology of crops, perennial crop viz. apple and stone fruits in different elevation zone of H.P.

Methodology used

A survey was carried out in Spitti of district Lahual and spitti of Himachal Pradesh for obtaining the farmers perceptions on Phenology of apple and temperate fruits. Based on existing knowledge and discussions held with farmers, scientists, local institutions officials viz; Panchayati Raj Institutions (PRIs) of districts, Both primary from farmers and secondary data were collected to draw inferences. These data were collected on well designed questionnaires during 2008-09 particularly when apple blooming was in full swing

Farmers perceptions on change in climate over time for apple and temperate fruit phenology

Table (34) portrays the perceptions of farmers regarding change in climate over time for apple and temperate fruits in Spitti valley of Himachal Pradesh. All the farmers residing in the sampled villages experienced or realized change in climate over a period of time in last 15 years. In 80 per cent of the studied villages, the farmers as a whole reported advancement in natural flowering of apple, temperate fruits and crop flowering around villages by a week time, whereas, remaining 20% farmers responded no advancement in natural flowering around villages. In the study villages 60 per cent farmers had perceptions of advancement in fruit setting by a week time and in 30 percent of responded delay in fruit setting by a week time. The ten per cent farmers responded increase in frequency of hail storms. There was increase in dry spell as the rain fall was decreasing and the frequency and amount of snow fall was also declining. As per the information collected, 90 percent of farmers reported decrease in snow fall in comparison to past. Occurrence of snow fall was higher (5 to 6 feet) in old days and there was also rise in temperature (both minimum and maximum). In all the sample villages, the size of glaciers was noticed to be reducing due to early melting and lasting for long time.

Due to climate change and favorable to cultivation of vegetable crops, 100 farmers have switched over to vegetable crops especially the garden pea which provides higher returns to them as compared to cereals.

Farmer' strategies to cope with climate change

Table (35) details out the different strategies adopted by farmers of the study area to cope with the climatic change. It can be seen from the table that farmers were now investing more on storage structure to store their produce safely against unfavorable climatic condition like rains etc. Farmers are switching over to low chill units apple varieties. Farmers were also growing short duration crops like pea, turnip and black lentil etc. these crops also provide higher returns than cereals in a short duration of time. Since in the study areas, rainfall is very scanty and that too not regular, only snow fall takes place. Moreover, the soils are sandy and highly drained. Farmers in 20 percent villages have made investment on harvesting of rain and snow water to cope with the climate change.

Table 34. Farmers Perception of climate of change in apple and temperate fruit phenology
(Dry temperate conditions of Spitti)

Sr. No.	Particulars of change	Percent response
1	Experienced or realized change in climate	
	a) Yes	100
	b) No	0
2	Advancement in natural flowering of fruits and crop flowering around villages by a week time	80
3	Delay in natural flowering of fruits and crop flowering around villages by a week time	30
4	Advancement in fruit setting by a week time	60
5	Delay in fruit setting period by a week time	30
6	Increase in frequency of hailstorms	10
7	Decrease in frequency of hailstorms	0
8	Occurrence of no hail storm at all	0
9	Shifting to vegetable crops (peas, turnip, black , (Lentil) due to warmness in climate	100
10	Increase in dry spell (6 to 8 month)	100
11	Decrease in dry spell	0
12	Frequency of rainfall	
	a) Increased	0
	b) Decreased	80
	c) Same	10
	d) Observed no rainfall	10
13	Reduction in snow fall from average of 5.5 feet in old days to 3.5 feet in recent days	90
	Frequency of snow fall	
14	a) Increased	20
	b) Decreased	80
15	Rise of 7 degrees in minimum temperature of (-20 to -6^{0} C)	80
16	Rise of 7 degrees in maximum temperature (15 to 22^{0} C)	70
17	Observed / noticed melting of glaciers	100

Source: Field survey, July-Sep, 2008

Table 35. Farmer's strategies to cope with climate change for apple &Temperature fruits

Sr. No.	Particulars	Percent response
1	Harvesting of rain and snow water	20
2	Cultivation of short duration, low chill var.	30
3	Cultivation of new vegetable crops	30
4	Investment on storage structure	90
5	Strategies to Shift the cultivation of fruits from low to high altitude	0.0
6	Planting of more golden apple plant for pollinations	60
7	Bringing more honey bees hive for pollination	70

Source: Field survey, May-June, 2008

Impact of Climate Change on Indigenous Honeybees as the Pollinators and on Apple Production in Himachal Pradesh.

Methodology used

A survey was carried out in Chamba, Kangra and Kullu districts of Himachal Pradesh where beekeeping with *Apis cerana* honeybees is in vogue since times immemorial and forms a part and parcel of livelihoods of certain communities. Based on existing knowledge and discussions held with beekeeping scientists, local institutions officials viz; Panchayati Raj Institutions (PRIs) and well-known beekeepers of districts, a complete list of Apis *cerana* colony rearers was framed. Similarly the well known wild honeybee (*Apis dorsata*) habitats in Chamba, Kullu and Kangra districts were identified in consultation with honey hunters. Both primary and secondary data were collected to draw inferences. These data were collected on well designed questionnaires during 2008-09 particularly when apple blooming was in full swing.

The findings of survey revealed that nearly 24% farmers started using bees for pollination. The rate was higher (60%) in Katrain and lower (7%) in Jallugran of district Kullu in Himachal Pradesh. In Seobagh 12% farmers used bees for pollination. Among users, 42% were using regularly and 58% occasionally depending upon their availability. The orchardists reported over eight times increase in apple production due to placement of honey bee colonies for pollination purpose. Experiments conducted in apple orchards with farmer's participation by UHF, Solan scientists at Jana village indicated that placement of bees increased yield to the tune of 77% (Table 36). Besides, an increase of more than 100 to 250 was recorded in the fruit set as results of placement of bee colonies in the apple orchards with poor and good pollinizers. A significant increase 35.48% in fruit production was found in orchard with bee colonies as compared to the orchard without bee colonies.

The climate change has brought adverse effect on the population of beneficial insects, the honeybees providing good pollinator services particularly to the apple crop in which productivity level is falling. The population density of *Apis dorsata* was found to be declining from 93/km^2 in 1993-94 to just 11/ km^2 in 2003-04 and to 08/km^2 in 2006-07. The study observed that the number of households rearing *Apis cerana* honeybees have also declined by 60% and of bee colonies by 28% over the years of 1993-94 to 2003-04 which shows that rearers have declined sharply than bee colonies. However, the total number of indigenous honeybees on sample villages declined to 325 in 2003-04 from 533 in 1993-94.

Decline in bee flora, shrinking forest areas and tampering by untrained people in an attempt to harvest honey were known the main reasons for the decline in their population reported by farmers.

The excessive and indiscriminate use of pesticides was another reason reported for decline in honey bees flora. The orchadists apply pesticides mostly at the time of pink bud stage. In the process of application, it falls on the flowers of brassica and white clover grown beneath apple trees. These flowers are frequented by the bees for collecting nectar and pollen and get affected.

Table 36. Impact of bee colonies (pollination) on fruit set and average yield of apples

Year	Place of conducting experiments	Fruit set (%)		Per cent change	Average fruit yield (t/ha)		Per cent change
		Without bee colonies	With bee colonies		Without bee colonies	With bee colonies	
2000	Research station	-	-	-	14 (PP) 24 (GP)	21.50(PP) 50 (GP)	53.57 108.33
2001	Larankelo	-	-	-	8 (PP) 18 (GP)	9.95 (PP) 25.10 (GP)	24.37 39.44
2001	Majhach	-	-	-	1	8	700.00
2001	Tharman	8 (PP) 32 (GP)	28 (PP) 70 (GP)	250.00 118.75	-	-	-
2003	Jana village	-	-	-	21.50	38	76.74
2004	Deoghra village	20.43	41.49	103.08	-	-	-

PP means poor/insufficient pollinizers (<15%); GP means good/sufficient pollinizers (> 15%).

Objective 3: Climate Change and medium range weather forecasting literacy among stakeholders.

Methodology used

One day awareness program for school children and college students and faculty on climate and save Earth on 22 April 2,009 were organized in collaboration with Ministry of Earth Sciences, New Delhi.

CENTRAL SOIL AND WATER CONSERVATION RESEARCH AND TRAINING INSTITUTE

DEHRADUN

Objective 1: To provide first estimate of impact of climate change (runoff, soil loss) on important commodities of selected watersheds of India based on literature review and expert judgment.

Work carried out and methodology used

The published work regarding impact of climate change on runoff and soil loss from about 500 ha watershed was carried out with respect to the methodology adapted by various workers, model used, results obtained and their interference with respect to climate change in India was collected, reviewed and observations were noted. The study area was restricted to 500 ha as all the Watershed Development Programme (WDP) of Govt. of India involving crores of rupees are executed on about 500 ha basis. About 50.83 m ha of land has already been treated with an expenditure of Rs. 19203.69 crores by the end of Xth plan (Pandey, C.M. and Singh Jagat Veer (2007) Watershed Development under River Valley Project and Flood Prone River Programmes-Future Strategies and Guidelines, J. Soil and Waterconservation.Vol.6, No.2, pp88-100).Planning Commission, Govt of India has projected that during XIth plan period about 20 m ha is likely to be treated with an out lay of Rs. 14000.00 crores. It therefore becomes necessary to understand the impact of any production oriented mitigation strategy on 500 ha basis because it is very likely to provide valuable planning strategy for future. It was observed during the literature review that neither in India nor in abroad any such study on impact of climate change on hydrology (runoff and soil loss) is available on about 500 ha area. Most of the study is on basin/catchment of macro area of more than 50,000 ha. It has also been observed that the data of runoff and soil loss from about 500 ha watershed is also not available with any agency which is needed for calibration and validation of any model selected for estimating runoff and soil loss from about 500 ha. Therefore the projected data has to be computed by suitably adjusting/modifying the data of small plot to watershed of 500 ha. The error if any is likely to be relative as the values are not absolute but relative.

Salient findings

Published data on the impact of climate change on Hydrology (runoff and soil loss) of about 500 ha is scantly and runoff and soil loss data from about 500 ha area (requirement for calibrating and validating of any hydrological model) is also rarely available. Therefore the available data of runoff and soil loss from plot studies of various land uses is to be used for computing output from about 500 ha watershed.

Objective 2: To calibrate and validate AVSWAT/Info Crop model for runoff, soil loss for key food crops in different Watersheds of the country.

Work carried out and methodology used

Modelling Climate Change Impact

SWAT and Infocrop models were applied to the database of Belura (Akola, Maharastra) watershed and the details of database and outputs are described below.

Preparation of *Weather data*

Weather data has been derived from PRECIS downscaled model prepared by IITM, Pune. The generic 30 days data has been converted to the actual days of the month for both baseline (1969-1990) and projected scenario (2071-2100). The GHG scenario A2a (CO_2=867 ppm) was used for crop simulation (Info crop).

SWAT Simulation

The Soil & Water Assessment Tool (SWAT) was used to simulate runoff and soil loss from Belura watershed. The DEM has been derived from the SRTM90 data (Fig. 30) and was appropriately processed to scale down to a higher spatial resolution. The actual stream derived from high resolution Google earth data was digitised and subsequently burnt on the DEM to exactly focus on the intended outlet. The actual area of the watershed was calculated to be 580.22 ha.

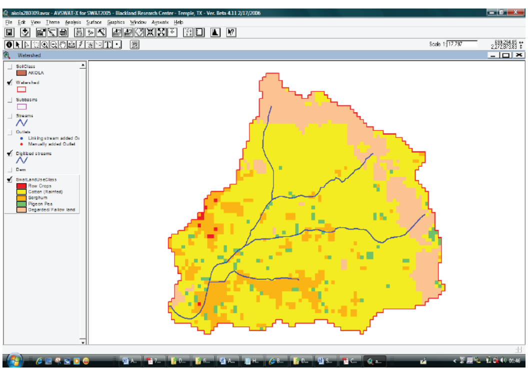


Fig. 30. Generated high resolution DEM from SRTM90 data with actual digitized streams from Google earth.

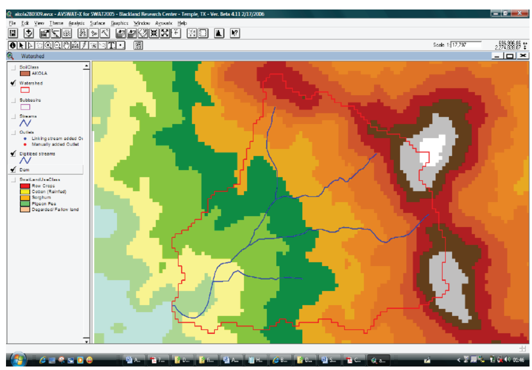


Fig. 31. Land use map of Belura watershed

Land use map

A land use map of Belura (Akola) watershed has been prepared (Fig.2). The major crops database has been collected from published literatures and internet. LISS3+PAN data merged with Google earth image has been used to classify the images based on comparable land-use patterns. The acreage of crops has been chosen based on relative membership of reflectance values to a particular crop's signature, time of the scene (Google Earth and LISS-III) and available literature.

The aerial coverage of land use is as follows (Table 37).

The soil database used for the simulation is derived from different sources like electronic sources, literatures etc.

Weather generator file

The weather generator file is the key for ascertaining missing variables in weather database used for SWAT simulation. The 47 years data of Buldhana was analysed to generate the weather generator file on a monthly basis.

Table 37. Land use classes of Belura (Akola, Maharastra) watershed

Landuse	SWAT_code	Area (ha)	% area
Sorghum	GRSG	67.99	11.72
Fallow/ Degraded	RNGE	93.32	16.08
Pigeon Pea	PIGP	13.52	2.33
Cotton (Rainfed)	COTP	404.00	69.63
Other agricultural crop (Row crops)	AGRC	1.39	0.24

Soil database

Crop database

The crop database used is as per the default database provided in SWAT model with some modifications based on available literatures. The management file in each HRUs or sub-basin is defined as per the average date of scheduling which encompasses the date of sowing, date of fertilisation and harvest date as per the locality and heat units were exactly input as per the crop physiological needs (derived from Info Crop to maintain parity in simulation).

Model run

The model was run for 3 situations;

1. Actual data (2002-2005)
2. PRECIS baseline data (1961-1990) downscaled
3. PRECIS projected data (2071-2100)

ANALYSIS OF MODEL OUTPUT

Based on the above simulation result (Table 38) it can be inferred that, comparison to baseline data the projected scenario has registered the changes as follows with the same cropping pattern and management activities.

The results/output provided here is from un-calibrated model merely from the baseline and projected scenario. Actual calibration requires time series of observed runoff and sediment data from the watershed, which is not available for the watershed under study. It is observed that the PRECIS baseline data on precipitation is quite over estimated (86% higher annually) as compared to the actual data of the weather station (Buldhana) and needs to be downscaled appropriately.

Table 38. Hydrological simulation result (SWAT) from Belura (Akola, Maharastra) watershed

Simulation variables	Actual weather data (2002-2006)	Baseline (1961-1990)	Projected (2071-2100, scenario A2a)	% change in Projected value w.r.t to baseline (%)
Precip (mm)	563.6	1048.6	1559.5	48.72
Surface runoff q (mm)	11.89	210.4	632.33	200.54
Lateral soil q (mm)	0.03	0.49	0.77	57.14
Groundwater (shal. aq) q (mm)	36.92	252.04	374.86	48.73
Revap (shal. aq > soil/plants (mm)	5.78	8.64	11.69	35.30
Deep aq recharge (mm)	2.24	13.67	20.28	48.35
Total aq recharge (mm)	44.76	273.32	405.64	48.41
Total water yld (mm)	48.79	461.91	1006.37	117.87
Percolation out of soil (mm)	44.98	273.39	406.36	48.64
ET (mm)	444.4	552.2	507.9	-8.02
PET (mm)	2397.0	2387.3	2701.7	13.17
Transmission losses (mm)	0.05	1.02	1.59	55.88
Total sediment loading (t/ha)	0.129	2.301	9.724	322.60

Abiding by the PRECIS data, the present analysis of output revealed that, in the projected scenario, rainfall will increase by 48.72%, and PET values will rise by 13.17% over those in baseline years. However, actual ET will be reduced by 8.02%. This is irreconcilable to a finding of significant increase in yield level of the major crops of the region as mentioned elsewhere in the report. To understand this, the annual distribution of ET was analyzed corresponding to crops and it was found that ET has reduced by 35% between January to mid July occupied by the less productive crops which are basically from degraded or fallow land with range vegetation (annual crops) or major crops with less water requirement stage, However, the enhanced water requirement stages of major crops like cotton/ sorghum /pigeon pea will be coinciding with the months starting August and December (wet/ Humid zone of the calendar year) resulting in higher ET values (increase by 27%) than those in baseline years. This ET increase will be reflected in higher crop yield in the above crops as discussed elsewhere in this report.

The higher sediment loss (322%) is evident due to enhanced percentage of runoff (200%) during the projected scenario than that of the baseline. In the projected scenario it is expected total water yield will increase significantly by 118% of which groundwater contribution would be whopping 48%. This means better prospects for rabi crops from supplemental irrigation point of view from the groundwater reserve. Better management of runoff would enhance better moisture regime post *Kharif* season and may add on to ground water reserve for use during *rabi* season.

Computation of value of some meteorological based indices to describe climate change

In order to describe the climate change with r4espect to meteorological parameters Spatial information viz, longitude, latitude, altitude and climatic parameters viz rainfall, radiation index, evaporation, runoff, moisture index, aridity index, precipitation deficit etc. have been generated for each watersheds under study using daily weather data of thirty years extracted from nearby meteorological stations through best possible spatial interpolation (Table 39).These parameters are likely to explain the changes in the moisture stress and wetness conditions resulting due to change in the temperature and rainfall, the vital parameter of the climate change.

Salient findings

Under the same cropping pattern and management activities, surface runoff and sediment load are likely to increase by 200.6% and 322.6% under projected condition with increase in rainfall by 48.7%.

Deep aquifer recharge as well as total aquifer recharge is likely to increase by 48% under projected condition. Water yield is likely to increase significantly by 118% of which groundwater contribution would be whopping 48%. This means better prospects for *rabi* crops from supplemental irrigation point of view from the groundwater reserve.

PET is likely to increase by 13% while ET is likely to reduce by 8%. ET for the months January to mid July is likely to reduce by 35% where as there is likely increase in ET by 27% for the period of Aug to July is attributed to the trend discrepancies between PET and ET. In main growing season (monsoon), however, this trend is similar. PET due to its atmospheric affiliation has increased significantly during non-monsoon season; where as ET due to the lack of moisture availability during non-monsoon season (projected period) has dropped significantly.

For Akola condition, Sorghum and Cotton crops are likely to be benefited under projected condition with an increase in yield by 183 and 103% respectively. Yield of this crop are also likely to be more stable under projected condition.

Objective 3: To simulate the impacts of different scenario of climate change (runoff and soil loss) on crop production through GLP/optimization.

Work carried out and methodology used

In order to find out the total crop production of a watershed the Info Crop model was run and has been used to generate crop production data of some crops (cotton, sorghum and pigeon pea) of Belura watershed (Akola, Maharastra).

Crop growth simulation for major crops of Belura (Akola, Maharastra) watershed using Info Crop.

Information required for running Info Crop model viz, type of crop, varity, Soil properties, crop management practices etc. were collected from literature and not very specific to the watersheds under study. Necessary correction in Info Crop for different physiological coefficients of crop variety and soil properties were done through Masters. Daily weather data of baseline (1961-1990) as well as projected (2071-2100) from PRECIS model defaulted for 30 days in each month were corrected for actual number of days in different months. The early morning actual vapor pressure required to run *Info Crop* was computed from temperature and mean relative humidity data using FAO method (Allen *et,*

Table 39. Salient information of the watersheds under study

Parameters	KG-III Watershed (Nilgiri)	Belura watershed (Akola)	Almas Watershed (Uttarakhand)	Umiam Watershed (Barapani)	Jonainala Waterhsed (Keonjhar)	Salaiyur Watershed (Cimbatore)	Antisar Watershed (Kheda)
Longitude	76.65°	76.89°	78.20°	90.93°	85.69°	77.06°	73.16°
Latitude	11.388°	20.55°	30.47°	25.70°	21.69°	11.22°	22.99°
Altitude	2300m	311 m	2600 m	1200 m	341 m	400 m	98 m
Annual rainfall	1171 mm	796 mm	2370 mm	3262 mm	1268 mm	617.4 mm	820.2 mm
Radiation index of Dryness	1.455	1.844	0.505	0.396	1.165	2.827	1.886
Budyko Evaporation	958 mm/year	695 mm/year	1044 mm/year	1164 mm/year	944 mm/year	587 mm/year	721 mm/year
Budyko Runoff	213 mm/year	101 mm/year	1326 mm/year	2098 mm/year	324 mm/year	31 mm/year	99 mm/year
Budyko Evaporation	81.80%	87.40%	44.10%	35.70%	75.60%	95%	88%
Budyko Runoff	18.20%	12.60%	55.90%	64.30%	24.40%	5%	12%
Aridity	Subhumid	Semi-Arid	Humid	Humid	Subhumid	Semi Arid	Semi-Arid
Aridity Index	0.93	0.45	2.37	2.84	0.87	0.38	0.43
Moisture Index	-7 %.	-55 %.	137 %.	184 %.	-13%	-22%	-57%
Precipitation Deficit	92 mm/year	954 mm/year	-1369 mm/year	-2113 mm/year	183 mm/year	1014 mm/year	1075 mm/year
Climatic net primary production	Precipitation Limited	Precipitation Limited	Temperature Limited	Temperature Limited	Precipitation Limited	Precipitation Limited	Precipitation Limited

al 1999). Radiation data for baseline as well as projected condition from PRECIS, seems to have some anomaly as it contains some daily radiation lower than the minimum radiation possible for particular day (complete cloudy day). Daily weather data were converted to info crop format for use with the model.

Cotton, Sorghum and Pigeon pea are the major crops of Belura (Akola) watershed selected for study. Info Crop model was run for base line (1961-1990) and projected scenario (2071-2100). CO_2 concentration for base line period (1961-1990) and for (A2a) projected scenario (2071-2100) was taken as 370 ppm and 867 ppm respectively for running model. Daily weather data for baseline as well as for projected scenario were obtained from PRECIS model. Due to unavailability of current as well as projected scenario of insect-pest status, insect pest damage has not been considered.

Cotton yields are likely to increase significantly (more than double) under projected condition of 2071-2100 as compare to baseline (1961-1990). The increase is mainly attributed to increase in rainfall (48.7%) *i.e* decrease in water stress days and increase in CO_2 concentration (867 ppm). To segregate the effect of increased rain fall and elevated CO_2, Info crop was run for both the condition separately. Increased rainfall showed more prominent effect (85%) in increasing yield than elevated CO_2. Cotton in very responsive to irrigation and yield is highly restricted by limited water availability under rain fed condition. Yield under projected condition is also likely to be more stable than baseline condition as reflected in terms of lower coefficient of variation (CV) (Table 40).

Table 40. Change in Yield and coefficient of variation (CV) for baseline and projected scenario of major crops of Belura (Akola, Maharastra) watershed.

Crops	% increase in yield	CV (%)	
		Baseline	projected
Cotton	103	52.5	42.3
Sorghum	183	86.5	46.8
Pigeon pea	10*	21	27.2

*nonsignificant at 5% level of significance

Sorghum yield showed 183% increase under projected condition. Being C-4 crop it is likely to respond very positively to elevated CO_2 (867 ppm) combined with higher rainfall. Yield under projected condition are likely to be more stable as evident from lower CV.

There is no significant change in pigeon pea yield. There was slight positive response of elevated CO_2 but increased rainfall is not beneficial and hence likely to offset the positive effect of previous one. The higher CV under projected condition shows relatively unstable crop performance.

Cotton and Sorghum are likely to be benefited under projected scenario while Pigeon pea may suffer. The inferences drawn are subjected to correction considering current and changing insect pest damage scenario, likely change in crop management practices, changing soil status every year under higher rainfall etc.

Info Crop is being calibrated with crop data for other watersheds.

Salient findings

For Akola condition, Sorghum and Cotton crops are likely to be benefited under projected condition with an increase in yield by 183 and 103% respectively. Yield of this crop are also likely to be more stable under projected condition.*Pigeon pea* did not show any net effect of projected scenario in terms of yield but yield is likely to be more vulnerable under projected condition. The likely positive response under elevated CO_2 with less moisture stress are likely to be offset by considerable increase in rainfall (48.7%).

Objective 4: To quantify the suitability of various Watershed Management Measures for adaption to climate change (runoff and soil loss).

Work carried out and methodology used

The engineering soil and water conservation measures (other than agronomical practices and biological/vegetative measures ,which are not only cost effective but also fits in long term strategies to mitigate the effect of climatic variability) are more favoured as being short term measures as they are quick to response to the damage control. Further the biological and vegetative measures are also more effective in combination with engineering measures. The engineering soil and water conservation measures are costly and therefore require proper planning and design. As these measures deal with basically precipitation (runoff), the structural design has to be perfect in order for their stability. The structural design is mostly based on spill way dimensions (hydraulic design) which itself is based on expected runoff from the given point in the field/watershed. The expected runoff is computed under hydrological design. The most sensitive parameter of hydrological design is the expected precipitation over the field/watershed. Lesser the quantity and intensity of te rain fall, less will be cost of structure. An over designed structure will cost heavily and the under designed structure will be prone to failure. Therefore the information of 24 hr and annual projected rainfall are very important for the cost and stability of any engineering soil and water conservation measures.

An assessment has been made to estimate the requirement of material of various engineering soil and water conservation measures suitable in arable land (Fig. 32&33).

Bunding

The design of bunding is done for 24 hrs maximum rainfall of 10 year probability. It is based on the assumption that the runoff from a given area resulting from 24 hrs rainfall will be stored behind the bunding in case of contour bunding and will be safely disposed off in case of graded bunding. It is projected that about 17 percent additional earth work in bunding (contour or graded) will be required if the one day maximum rainfall increases by 20 percent. like wise about 32.9 percent additional earth work with increase in one day maximum rainfall of 40 percent and about 80 percent additional earthwork with increase in rainfall by 100 percent is projected. The following relationship has been developed between increase in one day maximum rainfall (%) and percent increase in earth work of bunding;

$$Y=0.784\,x+1.6$$

Where,

Y = Percent increase in earth work in bunding

X = Increase in one day maximum rainfall in percent

Trenching

The design of trenching is also based on one day maximum rainfall of 10 year probability. Few professionals recommend 100 percent storage of the runoff while few recommend 40 t0 80 percent storage of daily runoff in the trenches. The volume of earthwork is very high with 100 percent storage which is likely to be functional only for a day in 10 years. Instead 4-6 over flow in a year with only 60 percent runoff storage will reduce the cost considerably. One day rainfall of 100 mm with 60 percent of runoff and 100 percent runoff storage will require an earth work of about 6oo m^3 while 60 percent runoff storage will require about 360 m^3 of earth work thus reducing the earth work of about 240 m^3. The earth work of trenching is projected to be 20 percent more with 20 percent increase in daily rainfall and 40 percent more with 40 percent increase in daily rain fall. Thus the increase in earth work is directory proportional to the increase in daily rainfall. The following relationship has been developed between increase in earthwork and increase in daily rainfall in trenching;

Y = X , Where,

Y = Percent increase in earthwork in trenching

X = Percent increase in one day maximum rainfall

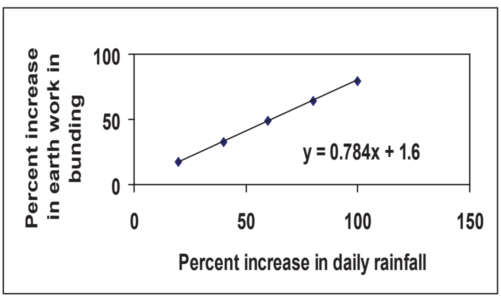


Fig. 32. Relationship between increase in daily rainfall (%) and earthwork (%) in bunding.

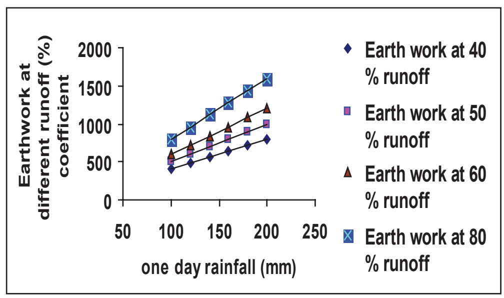


Fig. 33. Relationship among one day rainfall (mm) and earthwork (m^3) at different runoff efficient (%) for 100 percent runoff storage in trenching.

Salient findings

The cost of bunding and trenching has been assessed as per the projected increase in the rainfall. It is observed that about 17 percent additional earth work in bunding (contour or graded) will be required if the one day maximum rainfall increases by 20 percent like wise about 32.9 percent additional earth work with increase in one day maximum rainfall of 40 percent and about 80 percent additional earthwork with increase in rainfall by 100 percent is projected. Similarly the earth work of trenching is projected to be 20 percent more with 20 percent increase in daily rainfall and 40 percent more with 40 percent increase in daily rain fall. Thus the increase in earth work is directory proportional to the increase in daily.

ICAR RESEARCH COMPLEX FOR EASTERN REGION

PATNA

Objective 1: To calibrate and validate Infocrop model for key food crops in different agroclimatic regions of Bihar.

Work carried out – methodology used

Four sites were selected viz., Pusa, Madhepura, Patna, and Sabour in the agroecological zone I, II, III A, and III B respectively of Bihar to assess the potential effects of climate change and variability. The crop, meteorological and soil data for selected centers are collected from BAC, Sabour (Bhagalpur), IARI, Pusa, TDC, Dholi (Muzaffarpur), IRS, Madhepura, RAU, Pusa, and CRIDA, Hyderabad.

Salient findings

INFOCROP as a dynamic process growth model is validated and calibrated for selected locations. For Pusa (85.78°E longitude and 25.85°N latitude) the model has been validated for the rice, wheat (timely sown), maize (rabi and kharif) and chickpea crops Madhepura (86.23°E longitude and 26.11°N latitude). For Patna (85.24°E longitude and 25.58°N latitude) the model is validated for rice (medium duration) and wheat (timely sown). For Sabour (87.17°E longitude and 25.33°N latitude) the model has been validated for the rice (medium duration and wheat (timely and late sown) crops. Input data for model simulation is fixed and consecutively parameterized to the model required form. The grain yield simulated by the model was compared with observed yields and coefficient of efficiency worked out for all crops and locations.

Validation results for pusa are shown in Table 41.

Table 41. Validation results for Pusa

S. No.	Crop	Coefficient of Efficiency (%)	RMSE (kg/ha)	MAE (kg/ha)
1	Rice (Short duration)	71	234	197
2	Rice (Medium duration)	74	79	66
3	Rice (Long duration)	82	93	64
4	Wheat (timely sown)	84	166	137
5	Rabi Maize	45	513	372
6	Kharif Maize	62	174	122
7	Chickpea	52	25	21

Objective 2: To simulate the impacts of different scenarios of climate change on crop production in Bihar.

Work carried out-methodology used

After validating INFOCROP model for maize, wheat, rice and chickpea crops, grain yield was simulated for baseline climate. The scenarios were constructed from the available baseline weather data, based on the factors from HADCM3 GCM predictions. The monthly mean changes in maximum and minimum temperature were added in the individual days of the respective months, the percentage change in rainfall given in the scenarios was used to calculate precipitation for scenarios. Using this method the factors were incorporated into the baseline to generate scenarios. The model was run based on the agronomic practices used for validation. Predictions of PRECIS RCM have been acquired and the analysis of weather is being done by comparing the baseline weather of RCM and Observed.

Salient findings

For Sita variety of rice, an increasing trend in grain yield was observed as we move from 2020 to 2050 for all stations viz. Patna, Sabour and Madhepura except Pusa. For 2080 scenario, maximum reduction of 44% is observed at Pusa. Short duration variety (Saket-4) shows an increase in yield for 2020 at all stations ranging between 2-3% that reduces for 2080 ranging between 5% (Madhepura) to 31% (Sabour). Radha variety (Long duration) shows an increase upto 2050 at Madhepura and Patna while it decreases at Pusa and Sabour from the simulated yield of baseline with maximum reduction predicted is 43% for Pusa. For timely sown wheat, only Pusa shows a slight increase of 3% for 2020 scenario, rest of the stations shows a decrease in yield with maximum reduction for Patna to the tune of 39% in 2080 followed by Sabour at 38%.Decreasing trends have been observed for late sown wheat at all stations for all scenarios. The maize yield grown in rabi season is predicted to increase in future as per the scenarios taken into consideration for all stations. For zone I, the increase in yield is predicted to be 11%, 19% and 34%; the increase for zone II is predicted to be 9, 17 and 24%; for zone III (Sabour and Patna) also an increase in yield is predicted for 2020, 2050 and 2080 with maximum increase at Sabour. For maize grown in kharif season, decreasing trend of yield is predicted. All stations and scenarios show a decrease from the baseline yield with maximum reduction (31%) predicted for Sabour in both 2050 and 2080 scenario. Grain yield of Chickpea is predicted for Pusa that shows an increase from the baseline upto 2050 (15% for 2020, and 7% for 2050). In 2080 yield is predicted to decline by 2% from baseline grain yield. For Patna, chickpea yield may reduce in future to the tune of 13, 21 and 22% for 2020, 2050 and 2080 scenarios. Madhepura may show an increase in yield of chickpea nearly by 40% in 2080. Station and variety wise changes for rice crop are shown here.

Table 42. (A) Station wise changes in rice yield, and (B) Variety wise changes in rice yield

GCM Scenario	2020	2050	2080
Pusa	0.53	-1.52	-34.24
Madhepura	2.17	6.91	-15.29
Patna	1.67	4.48	-19.48
Sabour	-1.18	-4.71	-23.82
Saket-4	2.5	2.1	-12.1
Sita	0.7	3.8	-23.6
Radha	-0.4	-1.0	-33.4

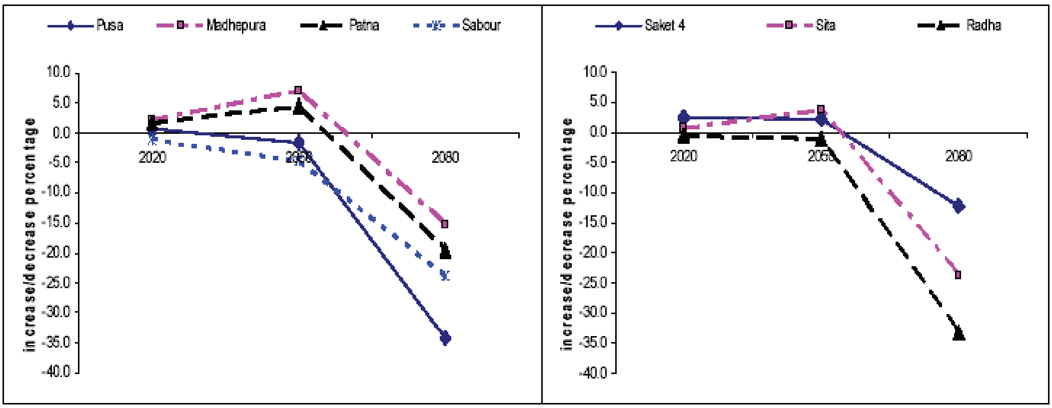


Fig. 34. Station and variety wise changes in rice yield for different scenarios

Weather analysis of the RCM data indicates a large difference in the rainy days and temperature between the RCM baseline and Observed baseline weather data. Keeping this in mind the factors are being calculated for incorporating the changes, predicted by RCM to generate the site specific scenarios. This will then be used to simulate the regional impacts of climate change at the selected centers.

Objective 3: To quantify the suitability of various agronomic and land and water management measures for adaptation to climate change.

Work carried out- methodology used

Adaptation strategies for rice wheat , maize and chickpea crops in the expected climate change scenarios have been applied ,which involves management practices like shifting of sowing date and minimizing the requirement of water and nitrogen to achieve the maximum benefit with the limited resources. Sowing dates have been shifted 7 days, 14 and 21 days advance for rice; 7 and 14 days advance for wheat; 7 days advance for maize and chickpea.

Salient findings

Advancing the sowing date of rice for short duration variety may increase the production of rice upto 2050 for all agro-ecological zones of Bihar, except at zone III B. Similarly in the medium duration variety an increment in yield could be predicted with the advancement of sowing date almost by 25% during 2080s for Pusa. Advancing the sowing of Radha variety by 7 days may prove beneficial for 2020 and 2050 scenarios but may result in marginal loss for 2080 scenario. In case of timely sown wheat 7 days advancement of sowing showed almost negligible increase in yield, while combining advanced sowing with 150 kg nitrogen application, model predicts an increase in yield for future scenarios. 14 days advancement of wheat sowing with nitrogen application @ 150 and 180 kg N has no or almost negligible effect on yield for all selected stations. Rabi maize showed an increase in yield with the advancement of sowing for all stations and for all scenarios except for Patna in 2020, similarly kharif maize showed an enhancement in yield with 7 days advanced sowing.

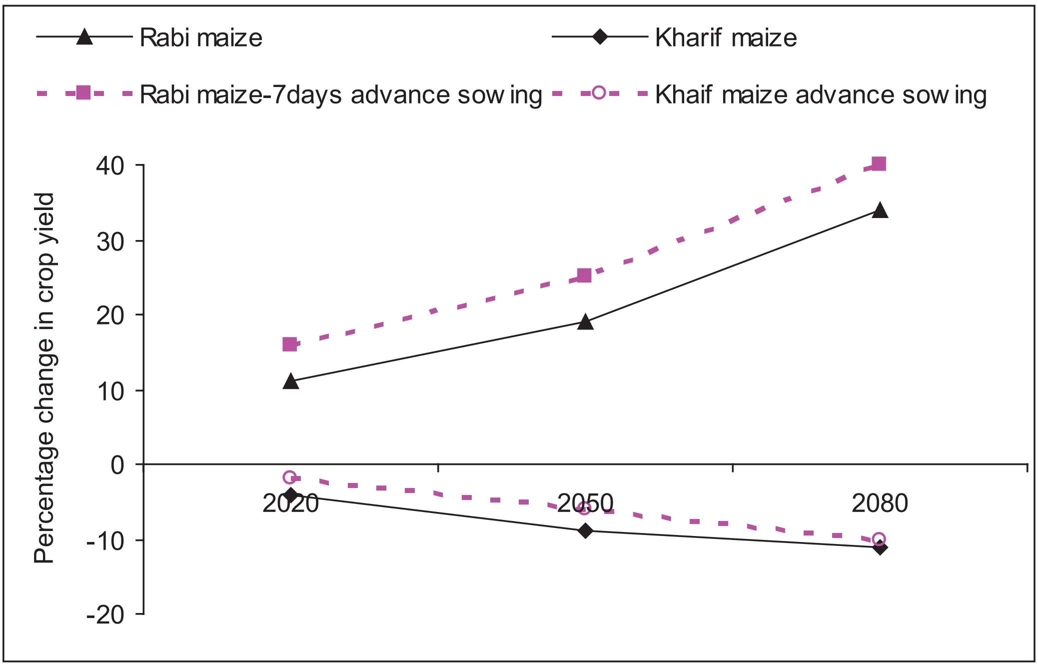


Fig. 35. Effect of advancement of sowing for maize at Pusa

Indigenous Technical Knowledge for designing agronomic practices relevant to climate change

ITKs, Indigenous Technical Knowledge is a sum total of knowledge and practices based on accumulated experiences of people from generation to generation of dealing with situations and problems in various aspects of life. Some ITKs related to climate and subtle changes in the atmosphere that affect the productivity of crops are being collected from farmers of villages situated in the districts of Patna, Nalanda, Bhojpur and Vaishali.

Objective 4: To develop integrated modeling framework for coupling hydrologic model with crop water demand, water allocation and socio-economic models.

In the ICAR Network project on climate change "Impact, Adaptation and Vulnerability of Indian Agriculture to climate Change", the Bhavani basin which is lying upstream of the Bhavanisagar Reservoir was selected for assessing the climate change impact on hydrology and water resources availability in the basin. For distributed hydrological modeling using the USGS Precipitation Runoff Modeling Systems (PRMS), basin was delineated into different HRUs using the following procedure. For dividing watershed into HRUs based on elevation, soil and landuse type, a DEM was generated (Fig. 36) in GIS environment using survey of India toposheets (1: 50000 scale). The toposheets were georeferenced, digitized and DEM was developed for the basin. Using the streamflow gauging stations as seed point, the basin was divided into three sub-basins. Different thematic layers like elevation, land use and soil maps were then overlaid and basin was divided into different HRUs and parameters were extracted using TNTmips for input to hydrological model.

As shown in Fig. 37, Upper Bhavani sub-basin with total catchment area of 1494.10 km^2 and straemflow gauging station located at Nellithurai was divided into 25 HRUs. The area of HRUs varied from 5.4 to 604.85 km^2. The elevation of the HRUs varied from 382.80 (HRU 21) to 2230.25 m (HRU 24) whereas slope varied from 4.85 (HRU21) to 63.16 % (HRU-15). The forest, agricultural and grassland area in this sub-basin account for 78, 14 and 8% of the total area. Similarly, the Moyar sub-basin with total catchment area of 1362.75 km^2 was divided into 35 HRUs. The HRU area varied from as low as 5.5 to as high as 568.80 km^2. The mean elevation of the HRUs varied from 442 (HRU 29) to 2269 (HRU 30) m and slope varied from 9.85 to 49.26 m. The sun-catchment is also dominated by forest land (74%) followed by agricultural (22%) and grassland area (4%).

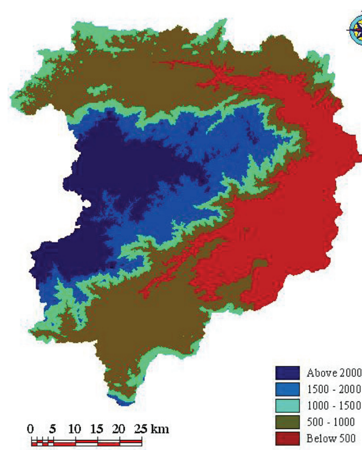
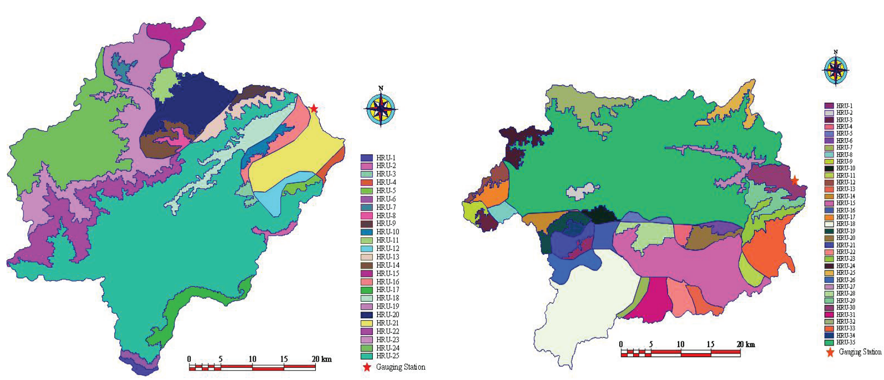


Fig. 36. DEM of Bhavani basin



(a) Upper Bhavani **(b) Moyar**

Fig. 37. Delineation of basin into sub-basin

The HadCM3 generated mean rainfall (mm/day) for 1980, 2020, 2050, and 2080 were extracted from four grid points covering the entire Bhavani basin was extracted and extrapolated using Inverse Distance method, and mean rainfall for 16 rain gauge stations (considered for hydrological modeling) was extracted. There is decrease in rainfall in most of the months in the basin both A2a and B2a scenarios. Maximum decrease of 45.20 and 51.90% was observed in the month of February 2020 under A2a and B2a scenario respectively (Fig. 38). Similarly, in 2050 there is maximum decrease in the month of February under both the emission scenarios. During the month of July and August there is increase (though less than 10%) in rainfall under both A2a and B2a emission scenario.

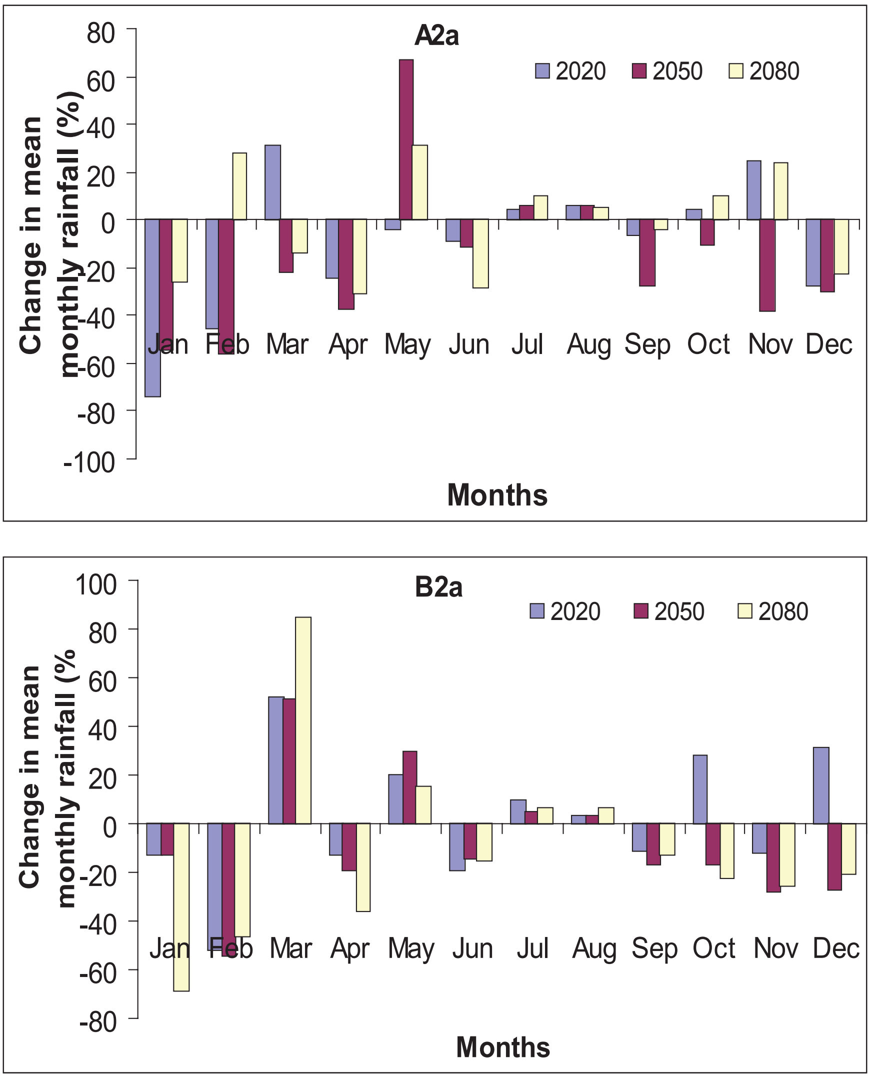


Fig. 38. Change in the mean monthly rainfall in the basin

NATIONAL DAIRY RESEARCH INSTITUTE

KARNAL, HARYANA

Objective 1: Thermal balance studies Thermal stress mitigation in cattle and buffaloes

Thermal balance and level of stress in cattle and buffaloes were assessed after exposure under natural environment and under controlled conditions. Heat loss and gains of heat were portioned for sensible and insensible loss. The results have been presented here.

i. Thermal stress mitigation

Thermal balance of cattle and buffaloes during summer and winter were monitored under natural environmental conditions as prevailed at Karnal. Cattle and buffaloes raised their body temperature during summer, however heat loss occurred through pulmonary and skin evaporation. In order to assess efficiency of thermal stress mitigation measures Six lactating buffaloes were kept under natural conditions (control) without fan cum cooling system and another six lactating buffaloes were maintained under the cooling system (experimental) for a period of six hours i.e. 10.00 am to 04.00 pm. Adaptation period of 15 days were given to the experimental group before the actual start of the experiment.

The average dry bulb temperature (°C) and relative humidity (%) were 36.7±0.2 & 42.6±1.5 respectively under natural conditions. The corresponding values in experimental groups were 35.8±0.1 & 46.7±1.4.The average dry bulb temperature decreased by 0.9° C and relative humidity increased by 5-6 % due to fan cum mist cooling system in open environmental conditions. The average wind velocity during the experiment ranged between 4.7- 6.9 km/ hr and sunshine hours ranged between 6.9-8.9. The average rectal temperature (RT) increased by 0.81°C in control buffaloes whereas in experimental buffaloes the increase was 0.4°C. The decline in core temperature was significant ($p<0.05$) due to the operation of fan cum cooling system for six hours during the peak hot hours of the day. The skin temperature (ST) at rump and hump regions was 36.70± 0.02 & 36.6 ± 0.02°C in control buffaloes. After the running of fan cum mist cooling system, ST at rump increased by 1.2 and 0.2°C respectively in control and experimental groups of buffaloes. Similarly at hump region the ST increased by 1.2 & 0.1°C, respectively in control and experimental buffaloes. The skin temperature at rump and hump regions significantly declined ($p<0.05$) in experimental animals as compared to control animals. Heat storage (kJ) declined by 60.19% ($p<0.01$) in experimental group of lactating cattle.

The respiratory frequency before start of the experiment in control and experimental animals were similar in the morning hours. Cooling system reduced the average respiratory requency by 11 breaths per minute compared to the control animals. However a nonsignificant decline in pulse rate was observed. The control and experimental buffaloes were monitored for Dry Matter Intake (DMI) during the experimental period. Average DMI in control buffaloes was 11.21±0.71 kg/day. The DMI increased by 8.2 percent in experimental buffaloes amounting to 12.13 kg/day. DMI /100 kg body weight was found to be 1.97 and 2.13 kg respectively in control and experimental buffaloes.

Milk Yield (kg /day) were recorded in both the control and experimental lactating buffaloes. A net increase in milk production of 0.8 kg/day in experimental group was observed indicating an increase in milk production of 12.3% as a result of fan cum mist cooling system.

ii. Use of depression of wet bulb (DWB) for cooling.

Depression in wet bulb (DWB) may be used as an index for turning on coolers in different parts of India during summer. Places like Kota, Hissar, Indore, Jhansi, Jodhpur, Mainpuri, Nagpur observe a depression of 10-18°C and adiabatic system of air cooling may be very effective for cooling livestock and livestock buildings. Initial experiments have demonstrated that simple wetting of cooler pads with a wind velocity of 2-4 km/hr can lower ambient temperature of sheds by 3-5°C, however at higher wind velocity the temperature drop may be 6- 8°C. Heat abatement system such as shades, fans, fog misters, and sprinklers are used to alleviate heat stress of high producing cows during summers. Thermal relief provided by these devices differs significantly at different places. Places with high WBD are more suitable for evaporative cooling and may help in reducing thermal stress of livestock by using evaporative coolers. The use of heat abatement system such as foggers or coolers can help in reducing THI to 70 or less from 80-85. But from July to September heat loss to environment declines due to increase of air humidity and low gradient for heat loss to air. The difference between dry and wet bulb is less than 5°C and T db is near 35°C. Low air velocity of 2-3 km /h is unable to dissipate body heat and animals are under distress. During hot-humid months THI for 24 h are in the range of 80-90. Adiabatic cooling becomes in effective and normal ceiling fan fitted in livestock buildings displaces air far less than that is required for dissipating extra body heat and maintaining optimum heat balance for production. High velocity blast fans (large and medium size) and mounted on sidewalls can help in reducing thermal stress on animals and body temperature within physiological limits of about 1°C of normal.

Objective 2: To measure influence of milk production level on methane emission from dairy animals.

i. Methane emissions in expired air of cattle and buffaloes

Emission of methane in expired air of cattle and buffaloes was continuously monitored for 24 hours using constant air flow pumps. Methane is emitted in expired air normally at much lower rates than that appear in eructation. The content of methane occasionally rise to more than 0.2% in expired air during an eructation from 0.02%. The number of eructation was also observed to increase during post feeding period.

ii. Interrelationship between Methane emissions and milk yield of crossbred cattle

Methane emissions of crossbred cows were measured using open circuit system and related with milk yield/day. High milk producing cows were observed to emit more methane than low producing cows.

iii. Methane emissions from Indian livestock manure

Emissions of methane from freshly voided dung and deposited under different conditions have been determined. Known quantities of freshly voided dung of different breeds of cattle and buffaloes maintained under similar management and feeding schedules were used for methane emission measurements. The methane emission from fresh dung of indigenous Tharparker breed of cattle was 8.22 mg/day and in Sahiwal was 9.06 mg/day. Emission of methane was higher, about two folds, in crossbred cattle (15.06 mg/day in Karan Fries) and Murrah buffaloes (14.45 mg/day). Methane emission from fresh dung on dry matter basis was also observed to be low in zebu cattle (45.00 to 46.00 mg methane/ 100 gm dung dry matter) as compared to crossbred cattle (96.204 mg methane/ 100gm dung dry matter). The annual methane emission estimates from dung of different breeds were 3.00 kg for Tharparkar, 3.3 kg for Sahiwal, 5.4 kg for Karan fries and 5.2 kg in Murrah buffaloes. Trends and patterns of methane release were similar in all the breeds, however the major effect came from dung itself with only a relatively small positive interaction with content of dry matter. Methane emission on storage increase after 8-10 hours of deposition and emissions were observed to be at peak in about 8-10 days after deposition. Diurnal fluctuations in methane emission were also observed and were related to ambient temperature rise. Emission of Methane was observed at peak during afternoon and thereafter it declined during night due to low fermentation activity and decline in ambient temperature.

Objective 3: Methane mitigation on the basis of indigenous technical knowledge

Methane emission from cattle and buffaloes maintained on different feeding regimens was monitored during different seasons. Methane emission from cattle and buffaloes was measured and overnight soaked mustard cake was used in the form of sanny on wheat straw based diets. The emission in the morning prior to feeding was measured and related for control and experimental groups. The methane emission due to sanny of mustard cake on wheat straw based diet in buffaloes was found to reduce enteric emission in buffaloes.

i. Effect of Mustard cake feeding on methane emission in buffalo calves

To see the effect of dietary mustard cake on methane emission an experiment was carried out for two months in buffalo calves. Buffalo caves of 8-9 month were fed with mustard cake. No significant difference was observed in methane emission 54.45 ± 6.37 vs 52.32±3.54 g/d/animal in two groups due to low level of mustard cake feeding.

ii. Effect of mustard cake feeding on Methane Emission in Goats

To see the effect of dietary lucrene + concentrated mixture on methane emission an experiment was carried out for 10 days in goats. A decline in methane emission was noticed due to mustard feeding in goats, however difference between two groups was non- significant. Feeding of mustard cake to goats caused an average decline of 11.96%, however decline in enteric methane emission from goats was 23.5% in the beginning of experiment.

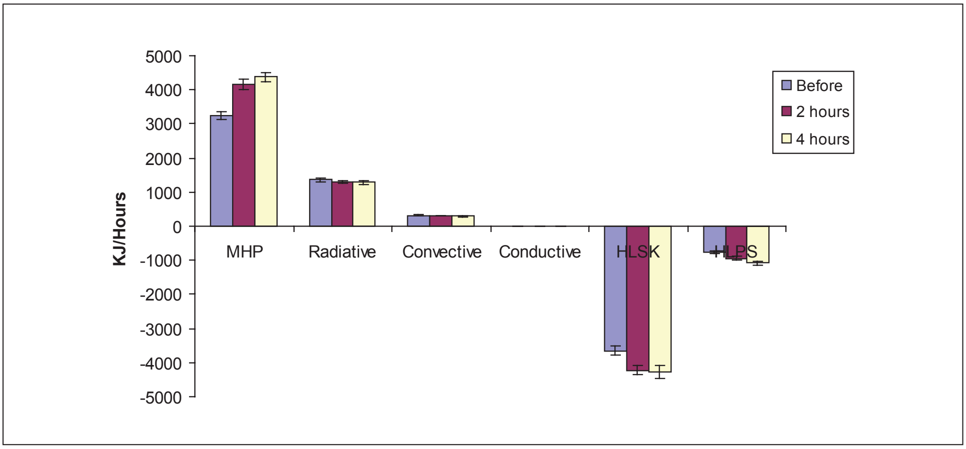


Fig. 39. Heat production and exchange in adult KF cattle at 40^{0}C temperature

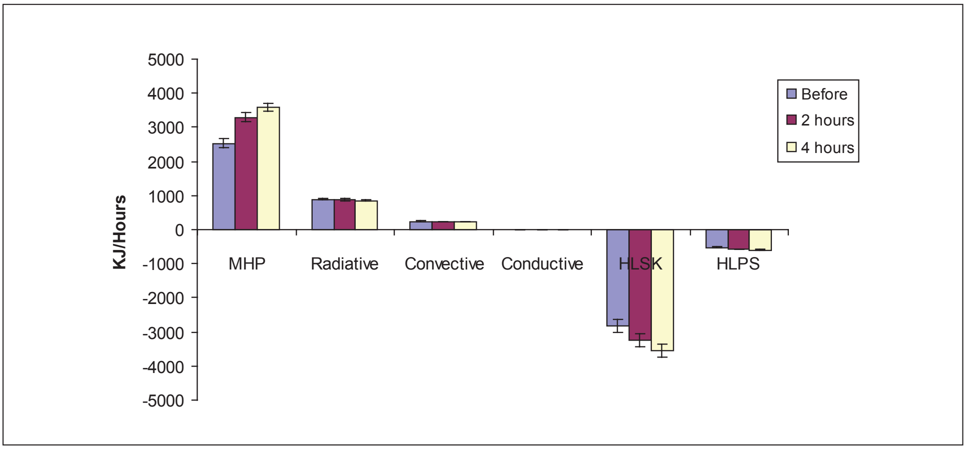


Fig. 40. Heat production and exchange in growing KF cattle at 40^{0}C temperature

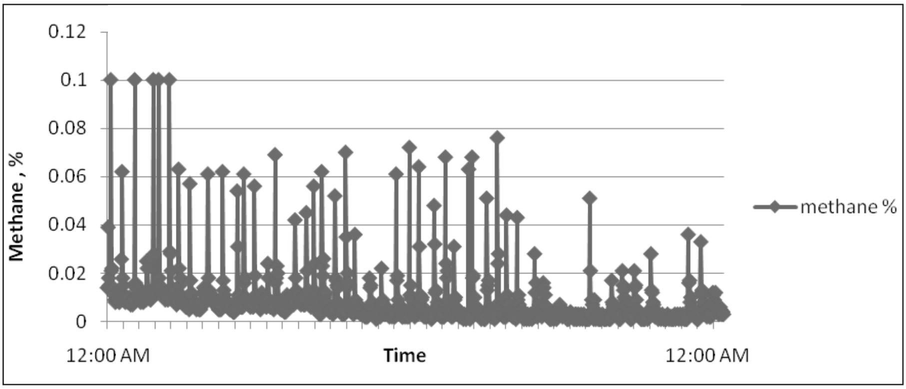


Fig. 41. Methane content in expired air of Murrah buffalo heifer

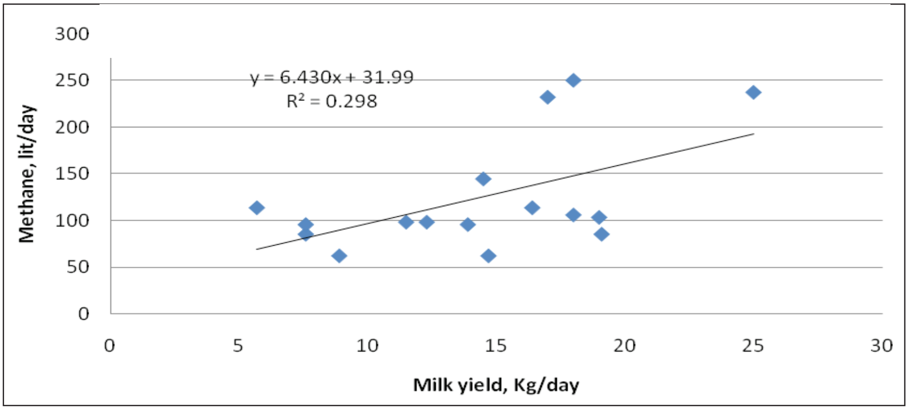


Fig. 42. Interrelationship between methane production and milk yield in crossbred cows

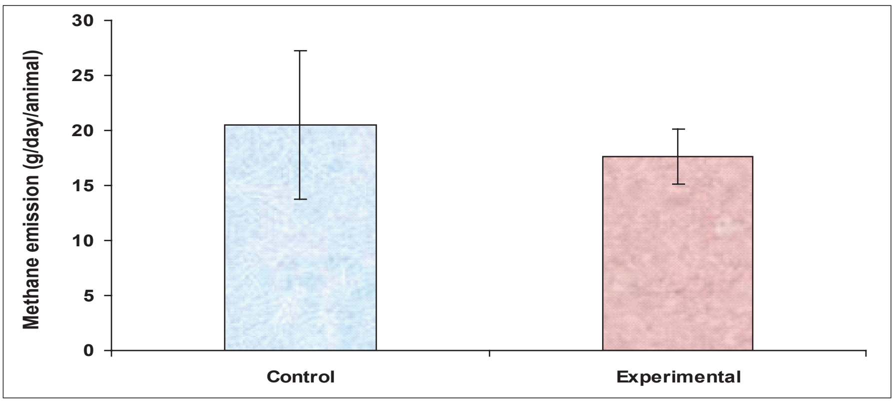


Fig. 43. Effect of dietary feed on methane emission in goat

Objective 4: Adaptation of livestock to Climate change: Role of HSP's Heat Shock Protein 72 expression in thermotolerant Sahiwal cattle and Holstein Friesian crossbred cattle.

The study on Sahiwal and Holstein Friesian crossbred (Karan-Fries) heifers was carried out to find out the pattern of expression of HSP72 and antioxidant enzymes *viz.* Mn-SOD and Cu,Zn-SOD under natural environment and at extreme temperature exposures in a climatic chamber (40ºC and 50% RH and 45°C and 50% RH for four hours). Presence of HSP72 protein in lymphocyte cell lysates was detected by SDS-PAGE (Fig. 44) and subsequent Western blotting (Fig. 45). Quantification of HSP72 protein in lymphocyte cell lysates was done by ELISA. Semi quantitative measure of relative expression of HSP72, Mn-SOD and Cu,Zn-SOD mRNA in lymphocytes was carried out by RT-PCR.

The study revealed that the basal level of HSP72 protein was higher in lymphocytes of Sahiwal (1.76±0.30 ng/µg) than that in lymphocytes of Karan-Fries (1.03±0.27 ng/µg) though the difference was not significant. HSP72 protein level increased due to thermal exposures. Karan-Fries exhibited higher magnitude of increase (106%) than Sahiwal (22.4%). Thermal load was observed to have a positive influence on induction of HSP72 protein (Fig. 46).

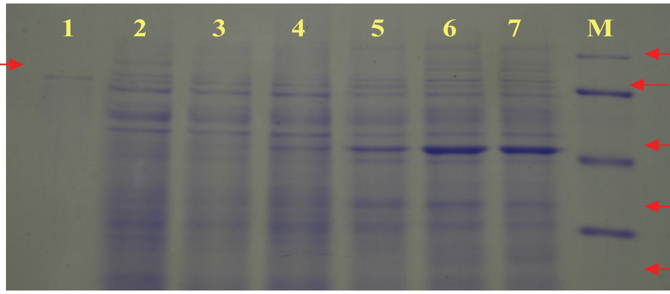


Fig. 44. SDS-PAGE of HSP72 (purified, sigma) and total protein in lymphocyte cell lysates of Sahiwal and Karan-Fries exposed at 45oC and 50% RH. Lane 1- HSP72 (purified), Lane 2- Before exposure, 3- 2 h, 4- 4 h (Sahiwal), Lane 5- before exposure, 6- 2 h, 7- 4 h (Karan-Fries), M- Molecular weight marker.

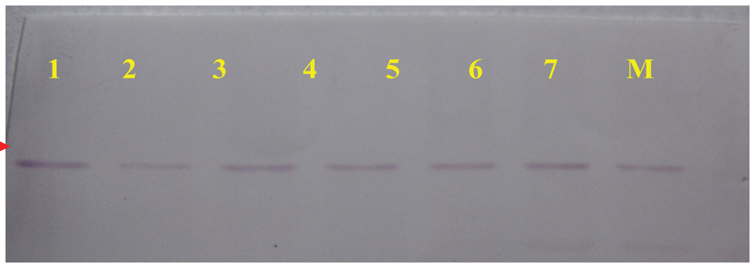


Fig. 45. Immunoblots of HSP72 (purified, Sigma) and HSP72 in lymphocyte cell lysates of Sahiwal and Karan-Fries exposed at 45oC and 50% RH. Lane 1- HSP72 (purified), Lane 2- Before exposure, 3- 2 h, 4- 4 h (Sahiwal), Lane 5- before exposure, 6- 2 h, 7- 4 h (Karan-Fries), M- Molecular weight marke.

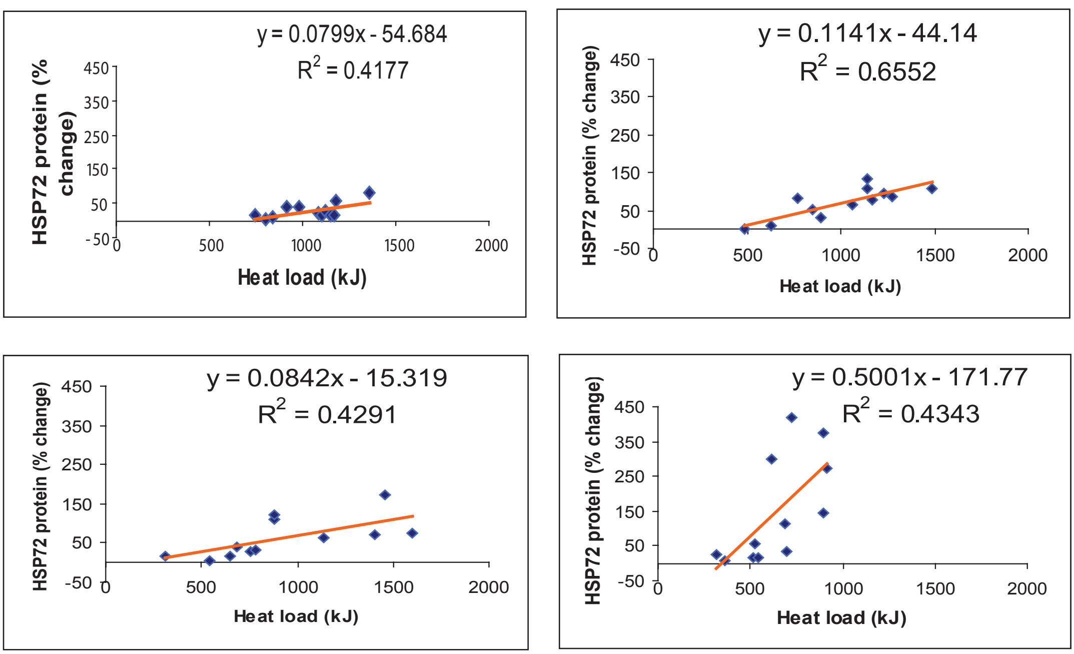


Fig. 46. Relationship between heat load and expression of HSP72 protein due to thermal exposures at 40°C and 45°C with 50% RH.

The level of expression of HSP72 mRNA remained low when the average ambient temperature was in between 15°C and 27°C. The expression of HSP72 mRNA increased significantly after heat exposure for 4 h in both the breeds of cattle. The magnitude of increase in the expression of HSP72 mRNA was higher in Sahiwal (122%) than in Karan-Fries (105%) during thermal exposure at 40°C and 50% RH. The expression of HSP72 mRNA limitedly fluctuated even after 4 h of exposure at 45°C and 50% RH.

The expression of Mn-SOD during heat stress (T_{max} 37.79°C) and cold (T_{min} 2.5°C) were found to be significantly different between both the breeds. Thermal load was found to have a negative correlation with Mn-SOD mRNA expression in Holstein crosses (Karan-Fries) after exposure at 40°C and 50% RH and in Sahiwal after exposure at 45° C and 50% RH. Extreme cold conditions increased Mn-SOD mRNA expression in both the breeds.

Expression of Cu, Zn-SOD mRNA remained stable in natural climatic conditions. Thermal exposure at 40 and 45°C with 50% RH in climatic chamber caused a positive change in expression of Cu,Zn-SOD mRNA after 4 h in Sahiwal and Holstein crossbreds.

Sahiwal and Karan-Fries exhibited minimal deviations in physiological responses during thermal exposure. Thermal exposure increased RR which was higher in Karan-Fries than in Sahiwal. The exposure at 40°C and 50% RH in climatic chamber caused a rise in RT by 0.88°C in Sahiwal as against a rise of 0.72°C in Karan-Fries after 4 h. However the magnitude of rise in RT at 45°C and 50% RH exposure was lower which was observed to be 0.61°C in Sahiwal as against 0.41°C in Karan-Fries primarily due to their adaptive response, in this case summer adaptation. Heart rate variability (RMSSD) declined during thermal stress in Sahiwal and Karan-Fries heifers.

Heat Tolerance Co-efficient of Sahiwal were 75.27±0.47 and 73.87±0.93 after 4 h of exposure at 40°C and 50% RH and 45°C and 50% RH, respectively. Corresponding HTC values in Karan-Fries were 72.00±0.81 and 72.93±3.37 respectively. DSI increased from 1.08±0.04 to 1.31±0.0.06 in Sahiwal and from 1.16±0.03 to 1.41±0.04 in Karan-Fries after 4 h of thermal exposure at 45°C and 50%. Sahiwal and Karan-Fries experienced mild to moderate degree of stress after 4 h of thermal exposure at 45°C and 50% RH (LSI 4.29±0.22 in Sahiwal and 5.13±0.16 in Karan-Fries).

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

KOCHI

Objective 1 : To conduct basic, applied and strategic research for quantifying the region – specific vulnerability of Indian marine fisheries to increasing climatic variability and climate change.

1.1 Simulations of increase in oil sardine biomass with change in fishing effort using the northwest coast ECOPATH Model.

Before 2004, the oil sardine *Sardinella longiceps* did not form regular fishery along the northwest coast (Maharashtra and Gujarat), as their abundance was low. The annul oil sardine catch was 2068 t during 1956-2004. The annual average catch increased to 13,014 t during 2005-2008 indicating that the oil sardine is poised for establishing a major fishery along the NW coast. Correlation of oil sardine catch with sea surface temperature (SST) and chlorophyll concentration indicates that the increase in the biomass/catch may be due to climate-related factors. To predict potential changes in the oil sardine abundance, and the impact this resource may inflict in the NW coast ecosystem in future, the ECOPATH model developed by CMFRI was used.

ECOPATH is a trophic mass-balance model. For this model, biomass, consumption, production and diet composition of 22 ecological groups, *viz*., phytoplankton, small zoolplankton, large zooplankton, benthic infauna, benthic epifauna, whale shark, *Acetes*, crabs & lobsters, penaeid shrimps, non-penaeid shrimps, benthic omnivores, cephalopods, small pelagic carnivores, small pelagic herbivores, bombayduck, midwater carnivores, small benthic carnivores, medium benthic carnivores, rays & skates, large benthic carnivores, large pelagics and dolphins were used as input parameters. The oil sardine was grouped in the ecological group *small pelagic herbivores*.

From the Model, the original biomass of oil sardine in the ecosystem (in the year 2006) was estimated as 0.02 tonnes km^{-2}. To delineate resilient and sensitive species in the ecosystem, simulations were attempted by gradually as well as abruptly increasing/decreasing the fishing effort over the years. The ECOSIM simulation showed that the biomass of oil sardine closely followed the change in fishing effort. In fact the highest increase in biomass (more than 3-times) occurred in the group small pelagic herbivores and with pulse fishing (rapid increase and decrease in fishing effort) this group showed immediate response by increase and decrease in biomass (Fig. 47). 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 indicated that other fisheries groups in the ecosystem may not be impacted immediately due to increase in the biomass of small pelagic herbivores. Figure 1 shows that small pelagic herbivores may have negative impact on mid-water carnivores alone, but not on other groups.

The model construction is progressing further for a better understanding on the effect of climate change on the northwest coast ecosystem.

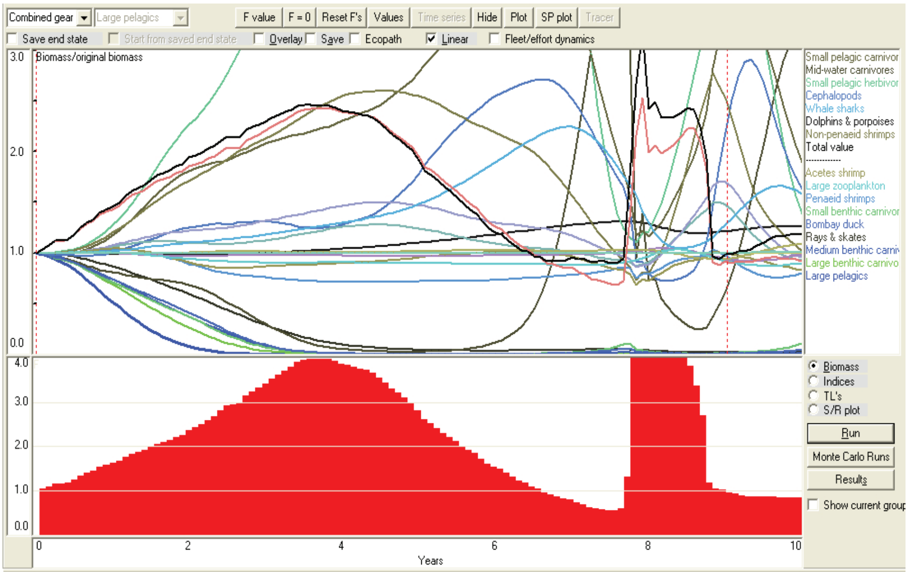


Fig. 47. Change in biomass of ecological groups in the NWC ecosystem with rapid increase in fishing effort and pulse fishing. Arrow-head in top panel indicates small pelagic herbivores and bottom panel (in red) simulated changes in fishing effort.

1.2 Temporal changes in the oceanographic parameters and fish catch along the Kerala coast.

To understand the temporal changes in the oceanographic parameters off Kerala, monthly average data on Sea Surface Temperature (SST), Salinity (S), Rainfall (Rf), Meridional Wind (V), Zonal Wind (U) and Sea Level (SL) were gathered for 1958-2008 from Asia-Pacific Data Research Centre (APDRC; http://apdrc.soest.hawaii.edu/). Data on Coastal Upwelling Index (CUI) were gathered from ICOADS for the years 1961-2007; and for chlorophyll *a* concentration for 1998-2008 from SeaWiFS. The data were averaged for five locations distributed at equal distance along the Kerala coastline. Data on monthly fish catch for the years 1958-2008 were collected from CMFRI, Cochin. It was found that (i) SST showed peaks at an interval of about ten years, and the number of anomalous months increased from 16% during 1961-1970 to 44% during 2001-2007; (ii) meridional wind speed (V) increased from 4 m/s in 1961 to 5 m/s in 2007; (iii) CUI increased from 300 in 1999 to 405 in 2007; (iv) chl a concentration remained at around 1.3 mg/m^3 during 1998-2007.

Analysis of quarterly moving averages of most of the oceanographic parameters showed good correlation with lag 3 of quarterly catches of oil sardine and Indian mackerel. For instance, the oil sardine and Indian mackerel catches had significant correlation with SST, S, Rf, U, V and SL (Table 43). Further analysis on the correlation between anomalies in the oceanographic parameters and standardized fish catches along the Kerala coast as well as for other coastal regions are attempted to develop fisheries predicton models.

Correlations

		Qrtly avg mperature	Qrtly avg Salinity	Qrtly avg rainfall	Qrtly avg sealevel	Qrtly avg Meridonia	Qrtly avg zonalwind	rtly avg CU moving avg	rtly avg CH	3 qrt lag oilsardine	qrt lag Mac
Qrtly avg tempera	Pearson Corre	1.000	-.352*	-.287*	.577*	.408*	-.307*	-.310*	-.680*	.334*	.166*
	Sig. (2-tailed)	.	.000	.015	.000	.000	.000	.003	.000	.000	.024
	N	200	200	72	200	200	200	88	41	185	185
Qrtly avg Salinity	Pearson Corre	-.352*	1.000	.673*	-.706*	-.535*	.553*	.500*	.595*	-.298*	-.196*
	Sig. (2-tailed)	.000	.	.000	.000	.000	.000	.000	.000	.000	.007
	N	200	200	72	200	200	200	88	41	185	185
Qrtly avg rainfall	Pearson Corre	-.287*	.673*	1.000	-.744*	-.618*	.640*	.605*	.486*	-.424*	-.120
	Sig. (2-tailed)	.015	.000	.	.000	.000	.000	.000	.014	.000	.316
	N	72	72	72	72	72	72	52	25	72	72
Qrtly avg sealevel	Pearson Corre	.577*	-.706*	-.744*	1.000	.829*	-.797*	-.708*	-.705*	.407*	.235*
	Sig. (2-tailed)	.000	.000	.000	.	.000	.000	.000	.000	.000	.001
	N	200	200	72	200	200	200	88	41	185	185
Qrtly avg Meridon	Pearson Corre	.408*	-.535*	-.618*	.829*	1.000	-.979*	-.779*	-.552*	.309*	.256*
	Sig. (2-tailed)	.000	.000	.000	.000	.	.000	.000	.000	.000	.000
	N	200	200	72	200	200	200	88	41	185	185
Qrtly avg zonalwir	Pearson Corre	-.307*	.553*	.640*	-.797*	-.979*	1.000	.766*	.492*	-.289*	-.275*
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.000	.001	.000	.000
	N	200	200	72	200	200	200	88	41	185	185
Qrtly avg CUI mo	Pearson Corre	-.310*	.500*	.605*	-.708*	-.779*	.766*	1.000	.651*	-.302*	-.393*
	Sig. (2-tailed)	.003	.000	.000	.000	.000	.000	.	.000	.009	.001
	N	88	88	52	88	88	88	91	25	73	73
Qrtly avg CHL	Pearson Corre	-.680*	.595*	.486*	-.705*	-.552*	.492*	.651*	1.000	-.364	-.269
	Sig. (2-tailed)	.000	.000	.014	.000	.000	.001	.000	.	.068	.185
	N	41	41	25	41	41	41	25	43	26	26
3 qrt lag oilsardin	Pearson Corre	.334*	-.298*	-.424*	.407*	.309*	-.289*	-.302*	-.364	1.000	.066
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.009	.068	.	.369
	N	185	185	72	185	185	185	73	26	185	185
3 qrt lag Mack	Pearson Corre	.166*	-.196*	-.120	.235*	.256*	-.275*	-.393*	-.269	.066	1.000
	Sig. (2-tailed)	.024	.007	.316	.001	.000	.000	.001	.185	.369	.
	N	185	185	72	185	185	185	73	26	185	185

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Table 43. Correlation between quarterly average values of 8 oceanographic parameters and catches of oil sardine and Indian mackerel along Kerala coast for the period 1958-2008; the catches of oil sardine and Indian mackerel are 3 (quarter) time-lag of the oceanographic variables.

1.3 Effect of seawater temperature on growth, decay and species composition of phytoplankton.

Seawater temperature is known to greatly influence phytoplankton growth, decay and species succession. Being the basic source of food supply to organisms higher in trophic level, changes in phytoplankton species composition and abundance will have serious impacts on the structure and function of marine ecosystems. To find out the impact of seawater temperature, and to assess their response in terms of cell density and multiplication rate. seven marine phytoplankton species (*Chaetoceros calcitrans, Chlorella salina, Tetraselmis chuii, Isochrysis galbana, Dicrateria inornata, Pavlova lutheri* and *Nanochloropsis* sp.) were grown in monospecies and multispecies enriched static cultures in the laboratory at different temperatures under controlled conditions, with and without the addition of nutrients.

All experiments were run in sterile glass flasks capped with sterile cotton plugs and aluminum foil. Fluorescent lamps were used to provide ambient lighting in tandem with the natural photoperiodicity.

Two sets of experiments at upper and lower limits of normal laboratory temperature (24°C and 29°C) were conducted. Each species was inoculated once and the growth and cell division patterns were continuously observed. Nutrients were added only once, at the time of inoculation in experiments without additional nutrient supplementation. Biomass, organic carbon levels, chlorophyll a & b concentration, nitrate, phosphate, pH and absorbance at different spectral wavelengths were recorded at each observation. For all the experiments, irradiance was maintained constant at 2 cal/cm^2/min by employing fluorescent tubes (photoperiod 12 h L:12 h D).

Monospecies static culture at various temperatures indicated that cell density and biomass were directly proportional to temperature elevations up to 32°C, beyond which cell death occurred.

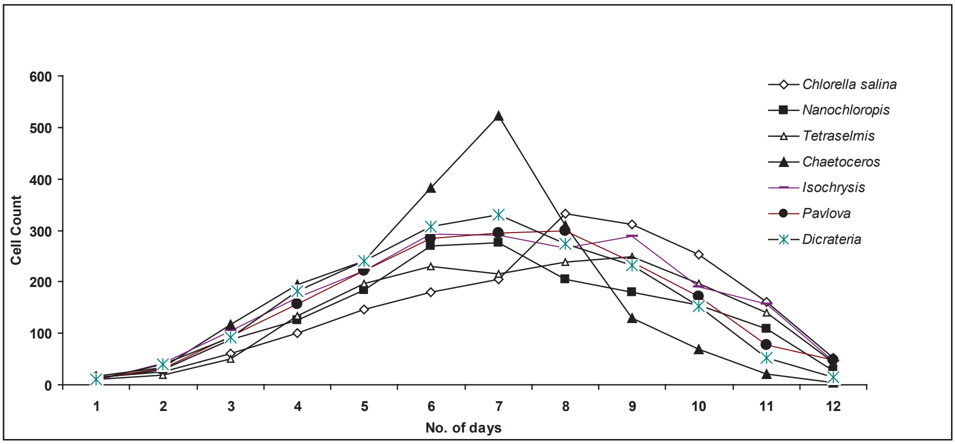


Fig. 48. Growth of marine microalgae at 24°C under laboratory conditions

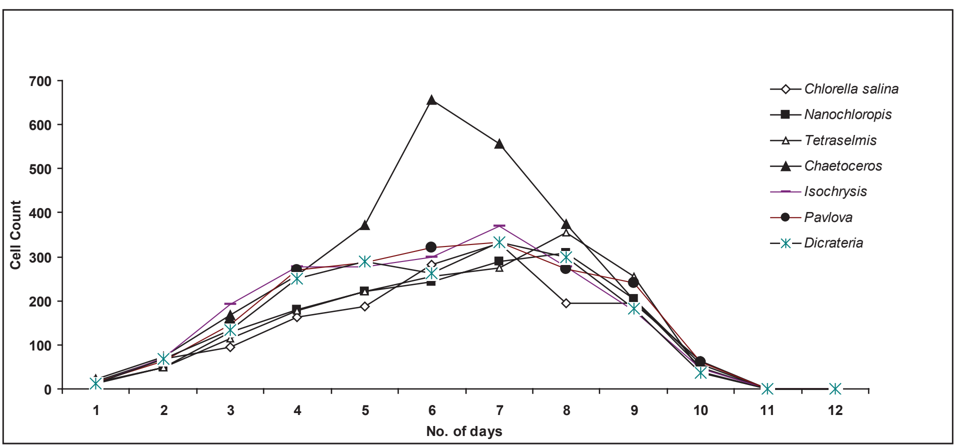


Fig. 49. Growth of marine microalgae at 29°C under laboratory conditions

When all the seven species of phytoplankton were cultured together at 24°C and 29°C, it was found that the microalgae grew faster at higher temperature, but the decay set-in early. At 24°C, the decay of one cycle set-in 12 days from the commencement of culture (Fig. 48), whereas the cycle was completed within 11 days at 29°C (Fig. 49). Significantly, the dominance ranking of different species of microalgae differed between the two temperatures. For instance, on Day 9 of the culture, *Chlorella salina* was the most abundant (310 cells/ml) at 24°C, whereas *C. salina* was the least abundant (200 cells/ml) at 29°C. This shows the temperature-related changes in the abundance and species dominance of phytoplankton, indicating the potential changes in the base of the food web in the marine ecosystems. Further experiments on the combinations of salinity and pH are in progress.

Objective 2. To develop adaptation strategies for minimizing negative impacts

Vulnerability of coastal fishing villages of Maharashtra to sea level rise

About 75 coastal fishing villages of Maharashtra are located within 100 m from the high tide line. This information has been collected from surveys undertaken by the field staff of CMFRI. To find out the vulnerability of these fishing villages to sea level rise, validation of available primary data from vulnerable fishing villages along Maharashtra coast was completed by ground truthing by using GPS. For ground validation, data were collected from GCPs (Ground Control Points) at different elevations from all 5 coastal districts of Maharashtra, and images were generated for all five coastal districts of Maharashtra state.

To find out the area likely to be inundated by 1 m sea level rise, Google Earth Professional software, and other basic softwares for large image processing, like OCR and WinZip, was used for enhanced image and data processing.

After geo-referencing these villages, three different SLR (Sea Level Rise) scenarios were created to determine critical area adjacent to the coast, likely to be submerged. Base mark (0 m), points at 0.3 m, 0.6 m and 1.0 m were obtained through software to calculate the perimeter and area for three SLR scenarios. All elevations are generated from mean sea level by the software. The results were validated by ground-truthing during field observations. A sample map thus generated for Juhu fishing village, Mumbai is given as Fig. 50. Consolidation of all the maps to identify vulnerable coastal fishing villages in Maharashtra is under progress.

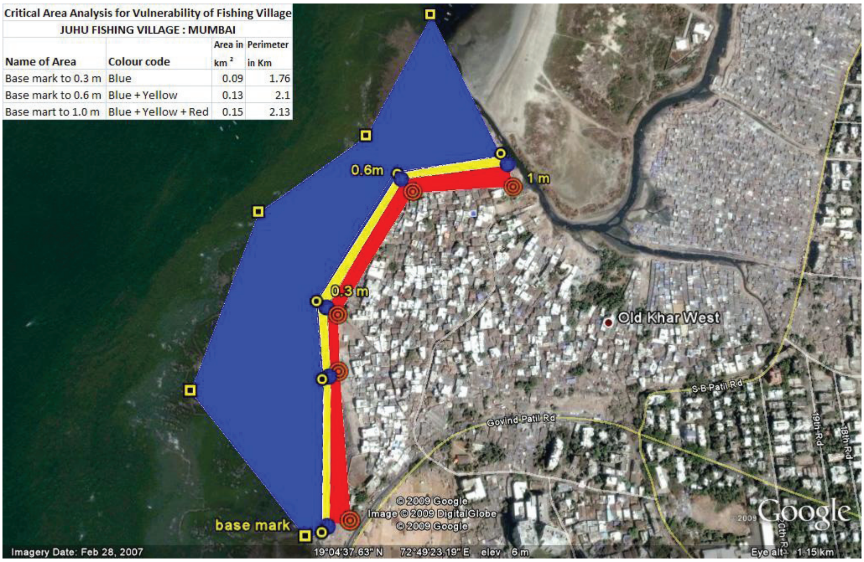


Fig. 50. Projected area of inundation of Juhu fishing village, Mumbai for three sea level scenarios; blue colour indicates 0.3 m, blue+yellow 0.6, blue+yellow+red 1.0 m rise in sea level.

Objective 3. To identify mitigation strategies

Estimation of carbon footprint by marine fishing boats

There are about 58,911 mechanised and 75,591 motorised fishing boats in India. They use diesel for propulsion and fishing. A survey was undertaken on diesel consumption by fishing boats operating from major fishing harbours in Cochin, Tamilnadu, Maharashtra and Gujarat. Data were collected from 1332 mechanised boats and 631 motorised boats by enquiring the fishermen, examining their logbooks and from the data collected from fishermen cooperative societies. From this, CO_2 emission by the marine fishing boats in India was estimated.

It is estimated that annual fossil fuel consumption by marine fishing boats is around 1380 million liters per year, which is equivalent to CO_2 emission of 3.6 million tonnes per year during 2005-2007. CO emission is generally considered as 10% of CO_2 emission, which is equivalent to 0.36 million tonnes per year. It was found that the mechanized boats emitted 1.67 tonnes of CO_2 per tonne of fish catch, and the motorized boats with outboard engine emitted 0.48 t CO_2 per t of fish catch (Table 44). Among the mechanised craft, the trawlers emitted more CO_2 (1.79 t CO_2/t of fish) than the gillnetters and dolnetters (1.41-1.45 t CO_2/t of fish). 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 by the marine fishing sector has substantially increased from 0.77 t CO_2 per tonne of fish catch in 1980 to 1.25 t per t of fish during 2005-2007 (Fig. 51), *i.e.*, 64% increase in CO_2 emission per tonne of fish caught in a period of 25 years.

Table 44. CO_2 emission (tonnes per tonne of fish catch) by marine fishing boats during 2005-2007

Fleet	CO_2 emission
Mechanised boats	1.67
Trawlers	1.79
Gillnetters	1.41
Dolnetters	1.45
Motorised boats	0.48

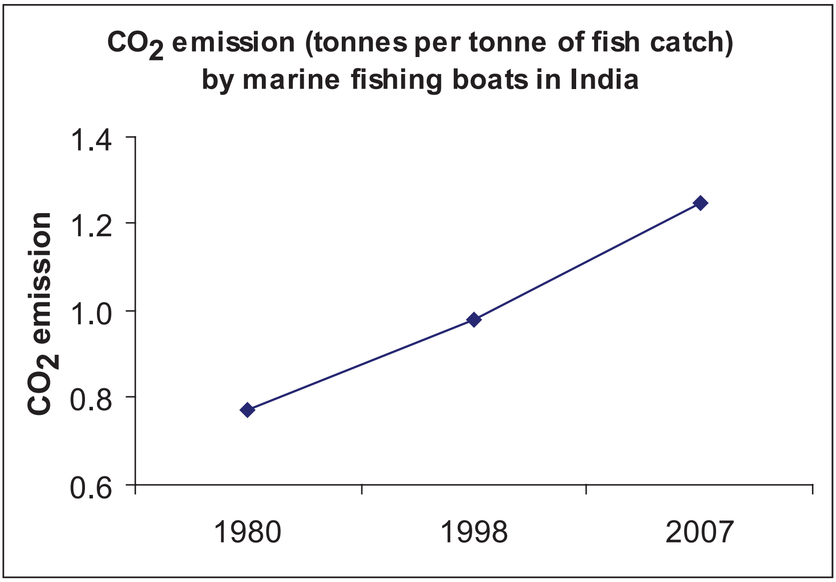


Fig. 51. CO_2 emission (tonnes per tonne of fish catch) by marine fishing boats during 1980, 1998 and 2007

Though marine fishing boats contribute only about 0.3% to the total CO_2 emission by India, there is scope to reduce the carbon footprint by the marine fishing boats by setting emission norms and improving the fuel efficiency of engines. Conservation measures such as (i) reducing and regulating the fishing effort, (ii) use of engine with appropriate horsepower, (iii) proper maintenance of engines, and (iv) reducing fish scouting time by using fish finding equipments would reduce CO_2 emission by marine fishing boats.

CENTRAL INLAND FISHRIES RESEARCH INSTITUTE

BARRAKPORE

Objective 1 : Development of models for predicting fish species richness of Indian River in relation to climate change scenarios.

One distinct model was developed by using suitable statistical technique (forward and stepwise regression procedures). In the model (a), data from all the 14 major river system in India were modeled using the three significant variables related to species area or size and climatic variability.

$\text{Log}(Y) = 0.119\,\text{Log}(X_1) + 0.743\,\text{Log}(X_2) + 0.185\,\text{Log}(X_3) - 1.481$ -------- (a)

Where Y= number of fish species, X_1=mean annual discharge, X_2=annual total rainfall, X_3=total area of the drainage basin.

Salient findings

- Fish species richness was correlated with three independent significant variables that together explained 73.3% of the total variability; the climate variability explained more of the Variations in species richness (eg. Annual total rainfall with standard coefficient or beta value 0.473, n=14, $p<0.05$) than did river size (discharge and total area of drainage basin with standard coefficient 0.361 and 0.358 respectively).
- We used this model to produce scenarios of fish species loss in 2020-30 on an average scale. We assigned potential loss of fish biodiversity in two different nested ways (i) first on the basis of predicted(simple trend analysis) rainfall due to climate change only (ii) then on the basis of predicted (simple trend analysis) discharge and rainfall combined.

Of these rivers four rivers are predicted to lose more than 7% of fish species under one or both scenarios. Based on available data it is predicted that, on an average scale, above 10% decrease in annual rainfall will occur in 76% of the river basins studied and above 10% decrease in discharge will occur in 90% of rivers by 2020-30, This may cause on an average 3% loss of fish species by climate change and water withdrawal in 2020-30.

Objective 2: Impact of Temperature Change on Growth of Indian Major Carp, *Labeo rohita.*

Procedure

Investigations were conducted simulating unit rise of temperature and its impact on the growths of Indian Major Carp, *Labeo rohita* fingerlings reared for five weeks at water temperature levels of 29ºC, 30ºC, 31ºC, 32ºC, 33ºC, 34ºC and 35ºC. in seven different thermostatic aquariums with 10 nos. in each and weekly removed from aquarium for measure body weight and the average body weight gained per fish.

Statistical analysis

Single factor ANOVA were performed to test the whether all treatment effects are alike.

The ANOVA result reveled that the growth rates differ significantly

($P=0.0003$, $F_{0.05; 6, 28} = 8.32$ and $F_{0.05, critical}=2.45$) at 5% level.

Critical difference= [√ (2*13.53)/5] *2.05=4.78.

The average specific growth rates of fish among temperature in our study ranged between 5.93% to 18.38% body weights per day.

Comparing critical differences, we find that

(i) The treatment (growth rate) at 34ºC temperature differs significantly (mean difference>CD) from each of the treatments at 29ºC,30ºC,31ºC,32ºC 33ºC and 35ºC.

(ii) The treatment at 33ºC differ significantly from each of 29ºC,30ºC,31ºC,32ºC.

(iii) The treatment at 35ºC differ significantly from each of 29ºC,30ºC,31ºC,32ºC.

(iv) All the remaining differences were not significant (mean differences<CD)

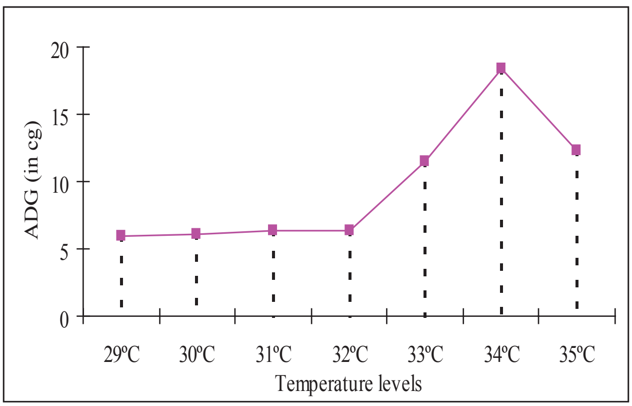


Fig. 52. SGR in different temperature level

Conclusion

The growth rates differ significantly ($p<0.05$) at different experimental water temperature levels.

The highest treatment mean effect is 18.38 cg due to the water temperature 34ºC.i.e. The fish reared at 34ºC grew significantly faster (18.38 cg in a day) than those at 29ºC, 30ºC, 31ºC, 32ºC 33ºC and 35ºC. Assuming these growth rates constant, it would take average 54-55 days for a fish to double in weight at 30ºC to 33ºC and 35ºC, but at 34 ºC it would take only 35-36 days.

The significant growth rate acceleration was observed from 33ºC water temperature. This trend was continued till 34ºC after which it subsided. After 34ºC water temperature, the growth rate was slashed in 12.33 cg at 35ºC water temperature level.

Objective 3 : Analysis of the impact of climate change on inland fisheries and their livelihood and development and selection of appropriate adaptive fish culture practices and fish species.

Comparison of Vulnerabilities and Quantifying the Impacts of Climate Change on Fisheries of South 24 Paraganas including Sundarban in West Bengal.

Methods

The Patnaik and Narayan method were applied for calculation of vulnerability index and the following source and variables of vulnerability were determined for 24 Parganas South.

Table 45. source and variables of vulnerability

Sources of vulnerability	Variables
Demographic	Density of population Literacy rate Infant mortality rate
Climatic	Variance in annual rainfall Variance in Maximum temperature Variance in Minimum temperature Flood Intensity
Fisheries	Total fish production Inland production Marine production Fish seed production Productivity of major craps Total fish landing
Occupational	No of fish farmers Fisherman population Industrial workers Marginal workers Non workers
Geographical	Total cultured area Coastal length Water area

For comparison purpose, the percentages of contribution to composite index for each source were derived and a simple ranking of those source indices (Average Index) were done.

Salient findings

Apart from the other source and variables of vulnerability for south 24 Paragans, above variables from five sources which are direct or indirectly related to the fisheries sector of South 24Paragans expressed only 11.11% of total District's vulnerability (Table 46).The fisheries sector contributing 26.54%, the occupational index contributing only 15% and the geographical location contributing 22.12% of the expressed vulnerability.

Table 46. Showing the source wise vulnerability indices and composite index for South 24 Parganas.

Source of VI	Average VI	Composite VI	% of Vulnerability	Ranking
Demographic	0.338675	0.111143	18.090%	3
Climatic	0.337987		18.053%	4
Fisheries	0.49690271		26.542%	1
Occupational	0.284498		15.196%	5
Geographical	0.414103		22.119%	2

Work in progress:

1. Data collection and Composite index calculation for each district of West Bengal in Fisheries context.
2. For comparison purpose, a simple ranking of the districts is being developing by using Beta Distribution and Multidimensional scaling technique.

Objective 4 : Socio-economics and Livelihoods of Small-scale Fishing: A case study in a fishing village by river Brahmani.

Work carried out - methodology used

A study was conducted to analyze the changing scenario of fishermen folk due to climate change, livelihoods implications of small-scale fisheries in Jajpur district of Orissa. With a rapid expansion of the population, changing climate and high fluctuations of river flows has resulted in difficulty in sustained fishing and viability of the family fishing in the region. Family fishing is critical for poverty alleviation and rural livelihood improvements. Since adaptive capacity is considered to be strongly linked to financial capital hence the inclusion of future economic scenarios is important in assessing potential vulnerability. The study addressed the socio-economics of family fishing, including opportunity costs of labor and capital used in the fishing efforts.

Methodology used

An in-depth economic analysis of family fishing was carried out following a village level participatory assessment in the village Sialia. Jajpur district in Orissa, The study adopted Participatory Rapid Appraisal (PRA) and individual household based questionnaires approaches to gather the field information and to carry out the economic analysis of family fishing activities. In addition to estimating cost and benefits of family fishing, comparison on climatic variability like rise in temperature and rainfall variation, fluctuations of river flows during the 90's scenario and the present were discussed and anlaysed and it's impact on livelihoods and related other concerns of the family fishing were also discussed among the community members following Focus Group Discussion and other tools of Participatory Rural Appraisal (PRA).

Result

The average income per day per family has come down from Rs./-300 to Rs./-200 while the cost of gears have doubled. Decreaase in average fish catch from 12-15 kg /day to 4-5 kg/day have resulted in lower returns from fishing activities.With increase in higher cost of living most fishers have decrease hours /day fishing and have involved in other non fishing activities like cattle rearing, poultry, bicycle repairing etc. with younger members of the family migrating to other profession outside the village. Since the fishermen are poor section of the society they have very small capital and they usually take small loan from money lenders to be repayed back along with interest after each season.With decreased income from fish catch each year payback of the entire loan amount has become difficult and the debt is carried forrowed the next year. Relatively low income have resulted alternate livelihood supports to many family fishers in the studied area. The field study in lower brahmani also showed that there is a very rapid population growth (over 3-fold) of small-scale fishers in the studied site over the last 20 years. Although the sale price of the fishes have increase the income per household (effort) has substantially decreased, mainly as a direct result of decreased fish catch constituting only 10% of higher valued carps.

Objective 5 : Use of GIS for the organization and display of spatial data on water resources of vulnerable area and combining a range of demographic, economic, environmental and climate data for developing on predicting models development.

Study area

South 24 Paraganas district of West Bengal situated between 20° 20' N to 22° 06' S 0latitude and 88° 20' E to 88° 60' W longitudes. There are five sub divisions (Alipore, Baruipur, Canning, Diamond Harbour and Kakdwip), 29 blocks and 7 Municipalities. The total area of the district is 8165.05 sq. km.

Famous mangrove forest Sundarban is in district. Out of 29 blocks only few coastal blocks have the Sundarban namely Gosaba, Kultali, Namkhana, Patharpratima and Sagar. The total fish production in the district during 2003 was 1,63,239 tons of of which 5,260 was contributed by prawns and shrimps. Ponds and tanks culture of shrimps and prawns contribute 6344 tons.

The culture practices followed are traditional, extensive, modified extensive and semi intensive. Paddy fields ranging in size from 0.5 to 10ha that are subject to tidal influence are auto stocked with wild seeds of mixed varieties of shrimp and fish.

Water resources of South 24-Parganas

Water resources of the district were delineated using IRS 1D PAN + LISSIII merged satellite data using supervised classification and visual interpretation.

Mapping reveal that 1060 water bodies are in the district having area more then 0.5 ha. Most of the water bodies are below 10 ha.

Due to limitation of the image resolution imageries the water bodies having area below 0.5 ha could not be delineated.

Fisheries potential

Table 47. No. of water bodies and their area in South 24-Parganas

Sl. No.	Class	Total			Perennial		
		Number	Max Area	Average Area	Number	Max Area	Average Area
1	0.5 to 10 ha	895	1899.5	1202.4	263	853.6	684.3
2	10 to 50 ha	107	2324.7	1585.6	76	1734.2	1290.5
3	50 to 500 ha	51	7553.4	5885.3	41	6523.6	5370.4
4	500 to 1000 ha	4	2457.4	1760.8	4	2457.4	1760.8
5	More than 1000 ha	3	4064.8	3113.5	3	4064.8	3113.5
	Total	1060	18299.8	13547.6	387	15633.6	12219.5

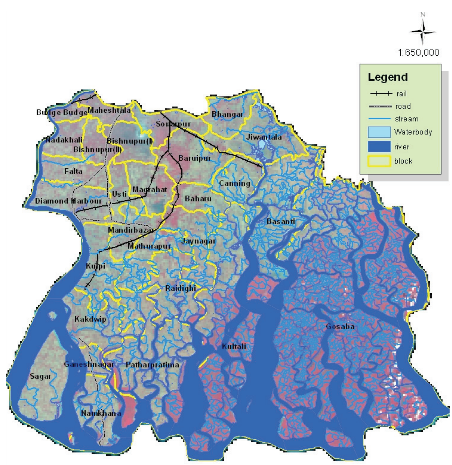


Fig. 53. Study area Impact of Sea rise

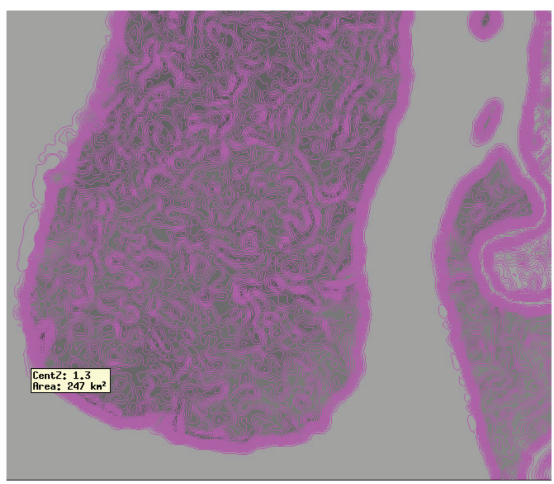


Fig. 54. Contour map of Sagar

To sea the impact of sea rise on coastal area, Sagar island was selected which is in block Sagar of south 24 pargana district. Digital elevation Model was generated from SRTM (Shuttle Radar Topographical Mission) of 90m spatial resolution data. Contour lines were created with the help of TNT Mips software in sub meter. The extended of land that will be submerged under scenarios of sea water rise in Sagar island in given following table II and map with contour is shown in fig 54.

Table 48. Sea rise and extent of submergence

Sl.No.	Sea rise in meter	Area submerged in km2
1	0.4	5
2	0.6	2
3	0.8	2
4	1.0	2
5	1.2	3
6	1.5	1

In Sagar island there are only 15 water bodies which have the area more then 0.5 ha and only three water bodies are in perennial in nature (Table 49). After overlaying the contour on water bodies layer its found none of the water bodies is coming under threat by sea rise up to 1.5 m. But after going through high resolution imageries its found various small water bodies less the 1000 sq. m. are under threat. It requires further investigation using high resolution to know the exactly how much water bodies are going to affect by sea rise.

Table 49. Water bodies of Sagra Island

Sl.No.	Classes	Total			Perennial		
		Number	Max Area	Average Area	Number	Max Area	Average Area
1	0.5 to 10 ha	10	20.5	11.1	1	1.8	1.8
2	10 to 50 ha	4	96.6	61.0	1	28.8	27.2
3	50 to 500 ha	1	160.3	141.7	1	160.3	141.7
	Total	15	277.4	213.8	3	189.9	170.7

TAMILNADU AGRICULTURAL RESEARCH INSTITUTE

COIMBATORE, TAMILNADU

The work report and results are presented below under each objective

Objective 1: To develop optimal land use pattern for different ACRs using Multi-Goal Linear Programming (MGLP) with inputs from

i) Vulnerability Index (VI) and

ii) Crop models

- Resulus form MGLP (Multi Goal Linear Programming) model indicate that it is possible to increase the total rice production by 2.41 million tonnes, which accounts for 47.62 per cent more than the existing current level from the different agro climatic zones of Tamil Nadu after by imposing all the constraints (land, water, technology, labour and capital). Net income of the farmers will also increase from 47.09 to 64.21 billion rupees. This is higher by 17.12 billion rupees and shares 36.35 per cent more income to our farmers in Tamil Nadu.
- When maximizing farm net income at the aggregate State level, when all constraints are included, the farm income is higher by about 47 billion rupees which constitutes 100 per cent higher than the existing level of income.
- While minimizing irrigation water when all constraints are simultaneously introduced to maintain the current level of production of all crops, water consumption is 13.81 billion m^3 in this scenario which shows that this will be the minimum water requirement for agricultural activities in Tamil Nadu. However, this is 44 per cent lower than the current water usage. Rice being the major consumer of water, consumes about 51 per cent of the total water requirement to maintain current level of its production.
- When agricultural area is minimized with constraints on all resources, the minimum agricultural area needed is 51.32 per cent to maintain the current level production.
- From the point of view of food security, the first objective namely, maximizing rice production should given top most priority and this objective should considered when constraints on all resources are imposed. In this situation, the rice production will be increased from about 5 million tonnes to 7.47 million tonnes for which current level of available resources are sufficient to achieve this level. This seems to be a feasible solution if about 43 percent of farmers adopt modern technologies (Technology 4 and 5) for which proper planning has to be made.
- The MGLP model was run to include all the five objectives on priority basis in the order: maximizing rice production, maximizing net income, minimizing water use, maximizing employment and minimizing agricultural area. In this case the maximum attainable rice production in Tamil Nadu is 6.72 million tonnes from the current level of production of 5.06 million tonnes while production of all other crops are maintained at their current level.

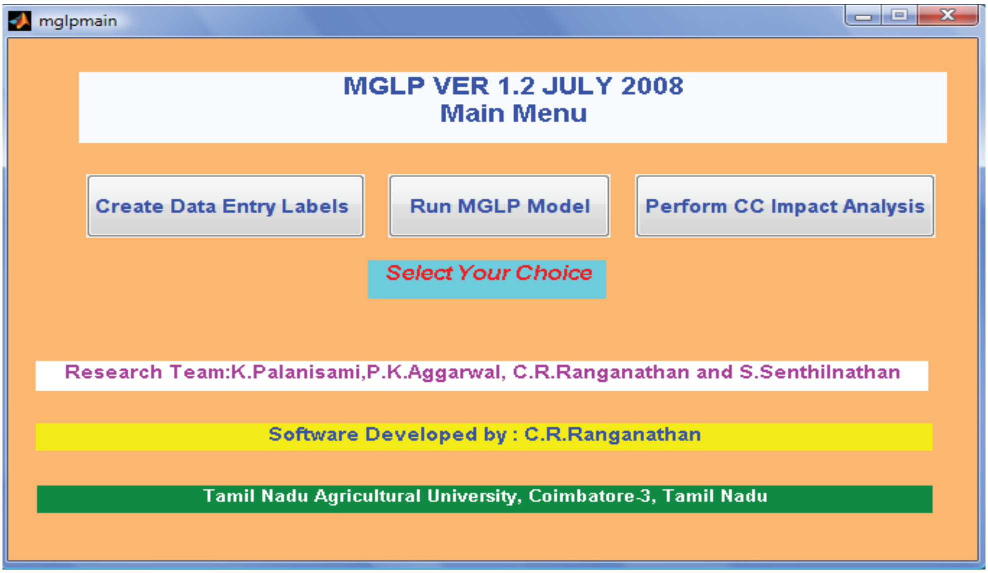
- Effect of three different climate change scenarios for 2020, 2030 and 2050 on the crop productivity and water requirement of following major crops i) rice ii) maize iii) sorghum iv) cotton v) groundnut and vi) sugarcane are estimated in the DSSAT model (Decision Support System for Agro Technology Transfer) was incorporated in the MGLP model to find the optimal allocation of land use. The simulated coefficients relating to productivity and water requirements of major crops derived from the DSSAT model were used in the MGLP model for all the scenarios.
- The results indicate that introducing all constraints simultaneously, the maximum rice production will decline to 6.65, 6.78 and 6.16 million tonnes in 2020, 2030 and 2050 respectively from the current level of 7.47 million tonnes.

Objective 2: To prepare an insurance chart for each of major agro climatic zone of Tamil Nadu based on premium linking vulnerability of major crops due to climatic change.

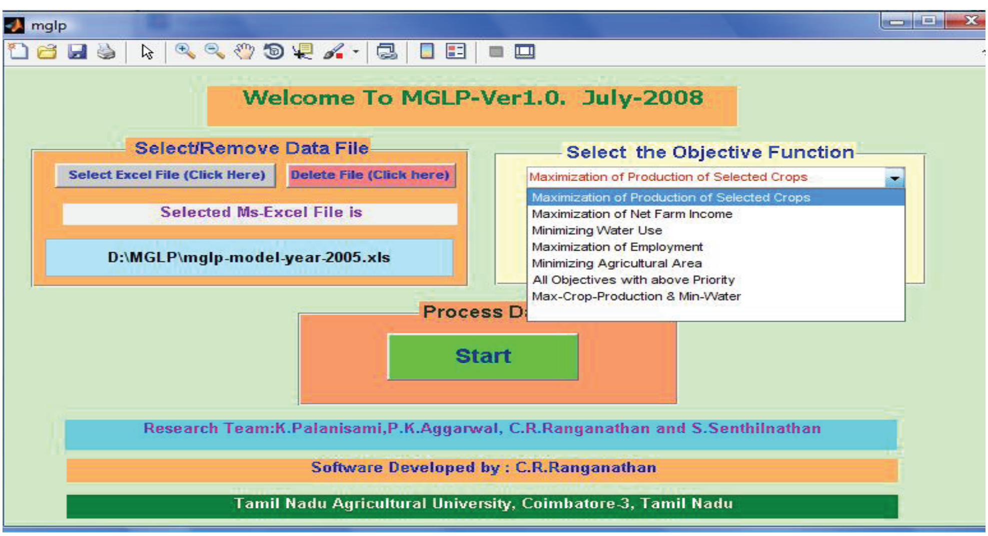
- Rainfall insurance policies are designed for the most vulnerable agro climatic zones of Tamil Nadu to protect the farmers against adverse effects of rainfall. Weather insurance is a mechanism, which protects the cultivators against anticipated shortfall in crop yield arising out of adverse weather incidence within a specific location and period.
- Rainfall Insurance policies are designed for the two main crops viz., groundnut and cotton for the most vulnerable southern region and groundnut and maize for the western zone. These two crops are more profitable than other crops, but they are more sensitive to drought. In addition, since the seeds are relatively expensive, some farmers purchase them using crop loans, but when harvest fails these loans are often difficult to repay. Hence, the payout structure for each crop is derived from using the historical weather data and different crop stages. Payout structure is a pre-defined benefit table, specific to a respective crop in a notified reference unit area. Payout structure defines the scale of payout for a given strike or upper threshold level and exit or lower threshold level.
- The coverage is mainly for the Kharif season (south west monsoon season), which is the prime cropping season running from approximately June to October. The contract divides the entire season into three phases *viz.,* sowing, vegetative and flowering or maturity period, and pays out if rainfall levels fall below particular strike or upper threshold levels. An upper and lower threshold is specified for each in all the three phases. If accumulated rainfall exceeds the strike level, the policy pays zero for that phase. Otherwise, the policy pays a fixed amount for each mm of rainfall below the strike or upper threshold level, until the exit or lower threshold level is reached. If rainfall falls below the exit level, the policy pays a fixed, maximum payout.
- The required premium, crop stages and their corresponding calendar period, strike and exit level, payout for each mm of rainfall and maximum lump sum payout for deficit rainfall insurance of groundnut and cotton crops for Madurai district are derived. The calculated premium is Rs 410 and Rs 375 for the groundnut and cotton crops respectively. In the case of groundnut the first phase extends up to one month. The policy pays zero if accumulated rainfall during this phase exceeds the 35 mm, otherwise Rs 133.33 for each mm of rainfall deficiency relative to the strike until the exit (5 mm) is reached. If rainfall is below 5 mm, the policy pays a fixed maximum lump sum payout of Rs 4000. In the same way, other two phases of both the crops are calculated.

Objective 3: To provide a training to all other participating centres in the software on MGLP and vulnerability index developed by TNAU centre.

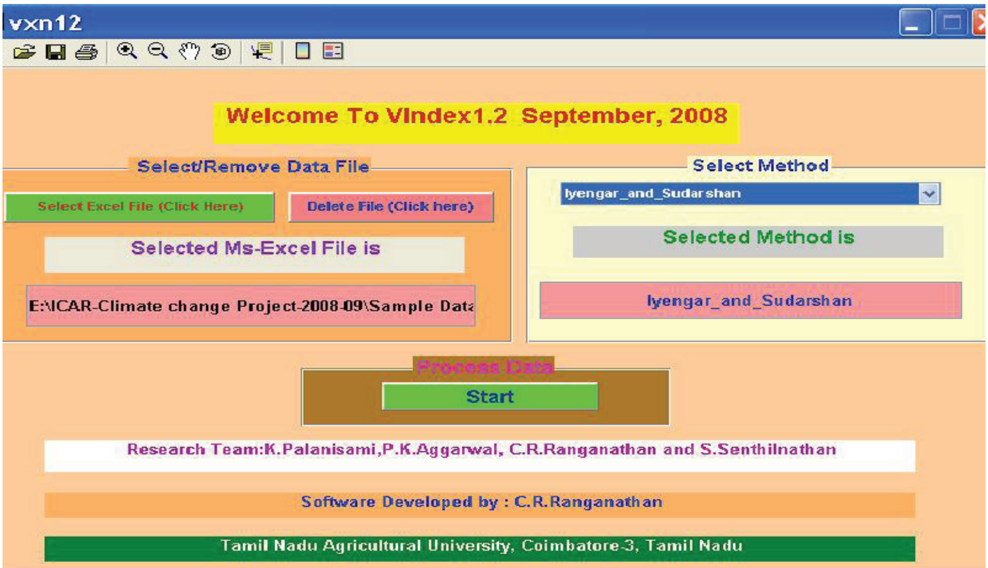
- A three days training program on MGLP modeling for studying the impact of climate change on crop production and construction of Vulnerability Index was organized during September 2008 for the benefit of all participating centres. About 15 scientists participated in the training program. The software developed by TNAU team was demonstrated to all the participants and it was supplied to all of them for their use.



- The software developed by TNAU team for MGLP model is as follows. The following figure shows the main screen of the software. It contains three sub-menus i) Create Data Entry Labels ii) Run MGLP model and iii) Perform CC Impact Analysis.



- The user has to click Run MGLP model, the following screen will appear. The user has to first click the '*Select Excel File*' button and then he has to select the database file (for example, mglp-model-year-2005.xls). The user can select any one of the 7 objective functions to run the MGLP model (see the figure below)



The software developed by TNAU team for Vulnerability Index (VI) is as follows. The following figure shows the main screen of the VI software.

Objective 4: To archive the future climate change scenarios for Tamil Nadu region from the output of model runs of précis with IITM support.

The précis model daily data sets for the baseline period that covers the data from 1960 – 1990 and also A2 and B2 scenarios with Sulphur for the period from 2070 – 2100 were obtained from IITM, Pune for Tamil Nadu Region. The climate change projection indicates that there is a possibility for increase in rainfall from 2075 onwards in almost all the agro climatic zones of Tamil Nadu. Larger shift in rainfall quantum is expected in Western and southern agro climatic zones which are exhibiting semiarid tropical climate in the current status. Model predictions says that there is possibility for doubling of rainfall towards the fag end of the century (2090) in the above two agroclimatic zones. There after the rainfall quantum starts declining in all the agroclimatic zones.

Maximum and minimum temperatures exhibit increasing trends in all zones of Tamil Nadu. However, warming is not uniform among the different zones. Projections indicate that the climate in all zones of Tamil Nadu will continue to warm, possibly by as much as 4.6°C by the end of the century (2100) above mean annual temperature (1961-1990). Compared to maximum temperature, minimum temperature is increasing more and the projected increase in minimum temperature for the year 2071 is from 2.51 to 2.71 °C over Tamil Nadu.

Objective 5: To adapt, calibrate, validate existing crop weather models to suit to the changing environment and use in the assessment of climate change.

A. Validation of INFOCROP model

The results on validation of Infocrop model for its accuracy in predicting the actual conditions for the three test crops viz., rice, maize and sorghum are presented in this section.

i. Rice

Field experiments conducted at TNAU during Rabi 2002 with the following treatments were used for validation of INFOCROP model:

Treatment details

Genotype and Dates of sowing

A. Genotype

G1 - CORH 2 (Hybrid) , G2 - ADT 39 (Variety)

B. Dates of planting

D1 - 19th September (3rd week), D2 - 26th September (4th week),

D3 - 3rd October (1st week),D4 - 10th October (2nd week), D5 - 17th October (3rd week)

Anthesis date in both hybrid and rice variety were under predicted by 1 to 5 days in most of the cases. However, it was exactly predicted in the hybrid when the crop was sown on 26th September. The model simulated the grain yield indicated both over estimation and under estimation of grain yield with different treatments. However, in most of the cases it was under estimated. There was no deviation in G1D5 and G2D4 treatments between predicted and observed grainyields. But the other treatments showed variation of more than 10 per cent.

ii. Maize

The results of field experiment conducted to identify the best sowing window within the potential season for irrigated hybrid maize (CO H_3) at Tamil Nadu Agricultural University, Coimbatore during Kharif 2001 season was used for validation of Infocrop Model.

Treatment details

Dates of sowing

M1 : 11.07.2001 M2 : 24.07.2001 M3 : 08.08.2001 M4 : 24.08.2001

The results indicated that INFOCROP model predicted the date of tasseling closely to the observed values. The maximum deviation observed was two days between predicted and observed values. The biomass yield was under estimated by the model, The difference between the observed and predicted values were high in the late sowing treatment (14%). Mean biomass yield deviation between observed and predicted was 8% in maize crop. The model has well predicted the grain yield of maize, The difference between the predicted and observed grain yield was very less and with 5% of deviation in M1 and M4 treatments and was wider in M2 and M3 treatments. Mean grain yield deviation between observed and predicted was 14.8% in maize crop.

iii. Sorghum

Field experiment was conducted at Tamil Nadu Agricultural University Farm, Coimbatore from June to November, 2005 to investigate the performance of sweet sorghum crop under different times of sowing and nitrogen levels. This experiment also has an aim to evaluate CERES – Sorghum model for times of sowing and nitrogen levels.

A. Main plot treatments (Times of sowing)

D_1 - June 8th, 2005 D_2 - June 23rd, 2005, D_3 - July 8th, 2005 D_4 - July 23rd, 2005

B. Subplot treatments (nitrogen levels)

N_1 - 90 kg N ha^{-1}, N_2 - 120 kg N ha^{-1}, N_3 - 150 kg N ha^{-1}, N_4 – control

The model predicted values of anthesis date closer to that of observed values. The difference between predicted and observed values was less than 10 per cent which indicated that the model predictions were within the acceptable limits. The model predicted the mean biomass yield as 9053 kg ha^{-1}, while the mean observed biomass yield was 8141 kg ha^{-1} with lesser than 10 percentage deviation between the predicted and observed values indicating the fitness of the model. The grain yield was also well predicted. The mean observed grain yield was 1874 kg ha^{-1}, while the mean predicted grain yield was 1899 kg ha^{-1}. The percentage difference between predicted and observed values was lesser than 10 per cent for all the treatments. The reason for the correct prediction might be due to the efficiency of the model in predicting the phenological stages, growth and yield parameters with better accuracy levels (< 10 % difference). The model has also performed well in partitioning the photosynthates well between the total biomass and grain yield. This indicates that the CERES – Sorghum model can be used for predicting sweet sorghum growth and yield parameters as well as for evolving management strategies.

B. Validation of DSSAT model

i. DSSAT model (CERES - SORGHUM MODEL) was evaluated for its satisfactory performance in predicting the actual conditions for sorghum is presented here under.

Treatment details

A. Varieties:

V_1- CO 26, V_2- CSV 15

B. Times of sowing

D_1-Dry seeding (sowing before the receipt of rainfall)

D_2-Monsoon sowing (sowing after the receipt of seasonal rainfall)

C. Nutrient levels

F_1-Control (No nutrient application), F_2- 40:20:0 kg of N: P_2O_5:K_2O ha^{-1}

F_3-60:30:0 kg of N: P_2O_5:K_2O ha^{-1}

The model predicted the date of anthesis very closer to that of observed one and the RMSE was 5.0 and the percentage of RMSE with observed values were with in the range of 10 per cent for all treatments. Per cent of RMSE with observed values was less than 10 per cent which indicated that the predictions were correct and the anthesis time also well predicted. The model under estimated the total biomass production and the difference between the observed and stimulated values were quite high. The deviation of observed value with predicted value was lesser under high level of nutrient application and as the nutrient level came down, the deviation got increased. The model prediction was very closer to the actual observed yield in the field for the treatments involving the nutrient levels of F_2 and F_3 irrespective of varieties and dates of sowing where as in case of treatments involving F1, the difference between the stimulated and actual observed values were comparatively higher due to under prediction of yield by the model.

ii. Validation of CERES-Rice model

Treatment details

A. Genotype:

G_1- CORH 2(Hybrid), G_2- ADT 39 (Variety)

B. Data of planting:

D_1-19th September (3rd week), D_2-26th September (4th week), D_3-3rd October (1st week),

D_4-10th October (2nd week), D_5-17th October (3rd week)

The model simulated value showed that model underestimated the biomass yield and the difference was higher and G1D3, G1D5. Overestimation as well as under estimation was observed.

Objective 6: To quantify the response of major crops (rice, maize, sorghum, cotton, groundnut, sugarcane) for future climate change (increased CO_2 and temperature and change in precipitation) on the growth, physiology, soil nutrient balance and water use efficiency at agro climatic zone level using crop models.

To understand the response of rice, maize, cotton and red gram crops to future climate change, INFOCROP model was run using base year weather data and B2 scenario for different time periods sating from 2070 to 2100. Impact of climate change on crop productivity of maize, cotton, red gram and rice indicated that the crop yields will go down due to increase in temperatures and variation in rainfall.

Project Staff

Co-Investigators

Indian Agricultural Research Institute, NEW DELHI

- **Name** : **Dr. S.D. Singh,** Principal Investigator
  Designation : Principal Scientist, Division of Environmental Sciences
- Name : Dr. Santha Nagarajan,
  Designation : Principal Scientist, Nuclear Research Laboratory
- Name : Dr. H. Pathak,
  Designation : Senior Scientist
- Name : Dr. S. Naresh Kumar
  Designation : Senior Scientist
- Name : Dr. Anitha Choudhary
  Designation : Principal Scientist, Division of Environmental Sciences
- Name : Dr. Madan Pal
  Designation : Senior Scientist, Division of Plant Physiology
- Name : Dr. Subash Chandra
  Designation : Senior Scientist, Entomology
- Name : Dr. Anjali Anand
  Designation : Senior Scientist, Nuclear Research Laboratory
- Name : Dr. Arti Bhatia
  Designation : Senior Scientist, Division of Environmental Sciences
- Name : Dr. Niveta Jain
  Designation : Senior Scientist, Division of Environmental Sciences
- Name : Dr. Bidisha Benerjee
  Designation : Scientist, Division of Environmental Sciences

Central Research Institute for Dryland Agriculture, HYDERABAD

- **Name** : **Dr. GGSN Rao,** Principal Investigator
  Designation : Project Coordinator
- Name : M.Vanaja
  Designation : Senior Scientist, Plant Physiology
- Name : M. Srinivasa Rao
  Designation : Senior Scientist, Entomology
- Name : A.V.M. Subba Rrao
  Designation : Scientist SS (Agromet)

- Name : M. Maheswari
  Designation : Pr. Scientist (Plant Physiology)- Co-PI
- Name : P. Raghuram Reddy
  Designation : Pr. Scientist (Plant Breeding)
- Name : S.K. Yadav
  Designation : Pr. Scientists (Biochemistry)
- Name : N. Jyothi Lakshmi, Scientist
  Designation : Sr. Scientist (Plant Physiology)
- Name : B. Venkateswarlu
  Designation : Director

Central Plantation Crop Research Institute, KASARAGOD

- **Name** : **Dr. S. Naresh Kumar,** Principal Investigator
  Designation : Senior Scientist, Plant Physiology (upto August 2008)
  : **Dr. (Mrs.) K.V. Kasturi Bai**
  HD, PB&PHT* (Project leader from Oct. 08)
- Name : Dr. D. Balasimha
  Designation : Principal Scientist
- Name : Dr. S. Naresh Kumar (from September, 2008)
  Designation : Senior Scientist

Indian Institute of Horticultural Research Institue, BANGALORE

- **Name** : **Dr. N.K. Srinivasa Rao,** Principal Investigator
  Designation : Principal Scientist
- Name : Dr. R.M. Bhatt
  Designation : Principal Scientist
- Name : Dr. R.H. Laxman
  Designation : Senior Scientist
- Name : Dr. K.S. Shivashankar
  Designation : Senior Scientist

CSK Himachal Pradesh Agricultural University, PALAMPUR

- **Name** : **Dr. Ranbir Singh Rana,** Principal Investigator
  Designation : Scientist
- Name : Mr. Vaibhav Kalia
  Designation : Assistant Professor
- Name : Mr. Sanjay sharma
  Designation : Assistant Extension Scientist

Central Soil and water Conservation Research and training Institute, DEHRADUN

- **Name** : **Er. K.P. Tripati,** Principal Investigator
  Designation : Principal Scientist, (Soil & WCE)
- Name : Dr. D.R. Sena
  Designation : Scientist Sr. Sclale, (S &WCE) at Vasad, Gujarat
- Name : Dr. H.B. Singh
  Designation : Principal Scientist, (Soils) at Vasad, Gujarat
- Name : Dr. Gopal Kumar
  Designation : Senior Scientist, (Agronomy) at Vasad, Gujarat
- Name : Er. Sridhara Patra
  Designation : Scientist, (S& WCE) at Deharadun

ICAR Research Complex for Eastern Region, PATNA

- **Name** : **Dr. Abdul Haris,** Principal Investigator
  Designation : Senior Scientist

Name : Dr. Abdul Islam
Designation : Senior Scientist

Name : Dr. R. Elanchezhian
Designation : Senior Scientist

National Dairy Research Institute, KARNAL

- **Name** : **Dr. R.C. Upadhyay,** Principal Investigator
  Designation : Principal Scientist (Animal Physsiology)
- Name : Dr. Sohan Vir Singh
  Designation : Senior Scientist, (Animal Physiology), DCP Division
- Name : Dr. Ashutosh
  Designation : Scientist SS, (Animal Physiology), DCP Division
- Name : Dr Harjeet Kaur
  Designation : Principal Scientist, DCN Division
- Name : Dr A.S. Chandel
  Designation : Principal Scientist, DES&M Division

Central Marine Fisheries Research Institute, COCHIN

- **Name** : **Dr. E. Vivekanandan,** Principal Investigator
  Designation : Principal Scientist & Head of Division
  Demersal Fisheries Division, CMFRI, Cochin

Name : Dr. N.G.K. Pillai & Head of Division
Designation : Principal Scientist, Pelagic Fisheries Division, CMFRI, Cochin

- Name : Dr. Sunil Kumar Mohammed
  Designation : Head, Molluscan Fisheries Division, CMFRI, Cochin

- Name : Dr. Mohammad Khasim
  Designation : Madras R.C of CMFRI, Chennai

- Name : Dr. V.V. Singh, Principal scientist
  Designation : Mumbai Research Centre of CMFRI, Mumbai

- Name : Dr. Jayasankar, Senior scientist
  Designation : Fishery Resources Assessment Division, CMFRI, Cochin

- Name : Sri. K. Vijayakumarn, Scientist (SG)
  Designation : Fisherie Environment & Management Division
  Mangalore R.C. of CMFRI, Mangalore

- Name : Dr. R. Sathiadhas
  Designation : Principal Scientist & Head, Socioeconomics &
  Technology Transfer Division, CMFRI, Cochin

- Name : Dr. Ramachandran
  Designation : Principal Scientist & Head, Socioeconomics &
  Technology Transfer Division, CMFRI, Cochin

- Name : Dr. Joe Kizhakudan
  Designation : Madras R.C of CMFRI, Chennai

Central Inland Fisheries Research Institute, BARRACKPORE

- **Name** : **Dr. Manas Kumar Das,** Principal Investigator
  Designation : Principal Scientist & Head

- Name : Dr. Prasanta Kumar Saha
  Designation : Principal Scientist

- Name : Mr. S.K. Sahu
  Designation :

Tamil Nadu Agricultural University, COIMBATORE

- **Name** : **Dr. C.R. Ranganathan,** Principal Investigator
  Designation : Professor, (Mathematics)

- Name : Dr. D. Suresh Kumar
  Designation : Associate Professor (Agri. Economics)

- Name : Dr. Geethalakshmi
  Designation : Professor (Agricultural Meteorology)

Research Associates and Senior Research Fellows

Indian Agricultural Research Institute, New Delhi (Co ordinating center)

Name	From (date)	Till (date)
Mrs. D.N. Swarupa Rani	1.04.2008	To date
Dr. Yashwant Das	1.06.2008	31.03.2009

Indian Agricultural Research Institute, New Delhi

Name	From (date)	Till (date)
Dr. Praveen Kumar Sharma (RA)	14.05.2008	31.03.2009
Mr. Vinod Kumar (RA)	08.05.2008	31.03.2009
Ms. Shilpi Mishra (SRF)	12.10.2007	31.03.2009
Ms. S. Kalpana (SRF)	08.10.2007	31.03.2009
Dr. Vinay Kumar Singh (SRF)	15.11.2007	31.03.2009
Dr. Sunil Kum Pandey (SRF)	11.02.2008	31.03.2009
Mr. Uttam Kumar (SRF)	08.05.2008	31.03.2009
Ms. Jyoti Jha (SRF)	23.09.2008	31.03.2009

Central Research Institute for Dryland Agriculture, Hyderabad

Name	From (date)	Till (date)
N. Manikandan (SRF)	2nd July 2007	9th Nov 2008
T. Satyanarayana (RA)	1st July 2008	Till date
V. RaviKumar (SRF)	1st December 2008	Till date
Mrs. P. Vagheera, SRF	4th June 2006	Till date
Abdul Razak, SRF	18th January 2008	Till date
G. Sree vani, SRF	April 2008	Mar 2009
Gayathri, SRF	April 2008	Till date

Central Plantation Crops Research Institute, Kasaragod

Name	From (date)	Till (date)
John Sunoj, V.S. (SRF)	6.7.2007	Continuing
Murali Krishna, K.S. (SRF)	9.7.2007	Continuing

Indian Institute of Horticultural Research, Bangalore

Name	From (date)	Till (date)
Miss G.M. Ashwini	15.12.2005	Continuing
Miss V.H. Prabhavathy	04.08.2006	Resigned on 6.09.2008
Miss. G.A. Geetha	18.02.2008	Continuing

CSK Himachal Pradesh Agricultural University, Palampur

Name	From (date)	Till (date)
Dr. Pankaj Chopra, RA	October, 2008	02.01.2009
Mr. Arun Kaushal, SRF	09.09.2009	March, 2009
Mr. Adarsh Kumar, SRF	October, 2008	March, 2009

Central Soil and Water Conservation Research and Training Institute, Dehradun

Name	From (date)	Till (date)
Sri Pravesh Saklani, SRF	05.03.08	Till date

ICAR Research Complex for Eastern Region, Patna

Name	From (date)	Till (date)
Ms. Vandana Chhabra	12.07.2005	Continuing
Ms. Anamika	09.12.2005	Continuing
Mr. Arvind Pratap	10.09.2007	Resigned on 23.02.09
Mr. Sandeep Biswas	11.09.2007	Continuing
Mr. Neeraj Kumar	20.06.2008	Resigned on 31.08.08

National Dairy Research Institute, Karnal

Name	From (Date)	Till (Date)
Dr. (Ms) Rita rani	11.09.2008	Continuing
Ms. Moloya Gohain	20.08.2008	Continuing
Ms. Nitika Rani	21.01.2008	28.02.2009

Central Marine Fisheries Research Institute, Cochin

Name	From (date)	Till (date)
Jasper B	25.06.2007	Continuing
Manjusha U	25.06.2007	Continuing
Remya R	23.07.2007	Continuing
Poonam Ashok Khandagale	26.09.2007	Continuing
Ratheesan K	24.07.2007	25.11.2008
Ambrose T.V.	08.08.2008	Continuing

Central Inland Fisheries Research Institute, Barrackpore

Name	From (date)	Till (date)
Sri Pankaj Kumar Srivastava (SRF)	05.01.2005	Continuing
Sri Sumanto Dey (SRF)	10.01.2005	Continuing
Md. Liakat Mondal (SRF)	07.09.2007	Continuing

Tamil Nadu Agricultural University, Coimbatore

Name	From (date)	Till (date)
S. Senthilnathan, RA	11.03.2007	Continuing
S. Govindaraj, SRF	20.06.2007	Continuing
N. Geethadevi, SRF	13.02.2008	Resigned on - 22.12.08
Guruswamy, SRF	04.07.2008	Continuing
Periyasamy, SRF	23.01.2009	Continuing
M. Leelamathy, SRF	01.02.2008	Resigned on - 21.12.08

Budget

Indian Agricultural Research Institute, New Delhi

Budget allocation and expenditure:

Centre	TA	RC	Contractual service	Workshop	POL	Total RC	NRC	Total (7+8+9)
1	2	3	4	5	6	7	8	9
IARI, N.Delhi	1.00	6.00	16.54	0.50	0.10	24.14	7.50	31.64

Central Plantation Crops Research Institute, Kasaragod

Budget allocation for 2008-09

Traveling Allowances	OTA	Recurring Contingencies	Contractual services	Workshop	POL	Total RC (1+2+3+4+5+6)	Non recurring contingency	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0	3.00	4.97	0	0.20	8.92	4.5	0	13.42

Total amount spent in 2008-09

Traveling Allowances	OTA	Recurring Contingencies	Contractual services	Workshop	POL	Total RC (1+2+3+4+5+6)	Non recurring contingency	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.398	0	2.035	4.257	0	0	6.69	0	0	6.69

Central Research Institute for Dryland Agriculture, Hyderabad

Budget allocation for 2008-09

TA	OTA	Recurring Contingencies	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	-	5.00	12.01	1.00	0.2	18.96	8.7	-	27.66

Total Amount Spent (In lakhs): (April, 08 to March, 09): **Rs.20.58***

*Rs.1.25 lakhs incurred over and above the sanctioned budget towards payment of arrears to the staff from overall savings.

Balance amount as on 31st March, 2009.

Total amount spent in 2008-09

TA	O T A	Recurring Contin-gencies	Con-tractual services	Work shop	P O L	Total RC (1+2+3 +4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.66	-	0.16	-1.25*	0.21	0.00	2.28	7.62		8.65

Indian Institute of Horticultural Research, Bangaluru

Budget allocation for 2008-09

TA	O T A	Recurring Contin-gencies	Con-tractual services	Work shop	P O L	Total RC (1+2+3 +4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	-	4.00	5.62	-	0.20	10.57	4.00	-	14.57

Total Amount Spent: (April,08 to March, 09): Rs. 9.97 lakhs

Balance amount as on 31st March, 2009. : Rs. 4.60lakhs

Total amount spent in 2008-09

TA	O T A	Recurring Contin-gencies	Con-tractual services	Work shop	P O L	Total RC (1+2+3 +4+5+6)	NRC	Institu-tional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	-	3.11	5.91	-	0.20	-	-	-	9.7

CSK Himachal Pradesh Agricultural University, Palampur

Budget allocation for 2008-09

Hono-rarium	Pay and Allow-ances	Travel-ing Al-lowances	Contin-gencies	Con-tractual services	Work-shop	Equip-ments	Works	Vehicle/ POL	Total
0.05		0.75	2.0	4.92	0	2.0 lacs	nil	0.20	10.92

Total Amount Spent in 2008-09 (Tentative-subject to slight change)

Pay and Allowances	Traveling Allowances	Contin-gencies	Contractu-al services	Work-shop	Equip-ments	Works	Vehicle/ POL	Total
	22522	199593	202249	-	nil	-	20000	523564

The Unspent amount: Rs. 567636 (The audited GUC is being sent by Comptroller CSKHPKV, Palampur)

Central Soil and Water Conservation Research and Training Institute, Dehradun

Budget allocation for 2008-09

Traveling Allowances	OTA	Recurring Contingencies (R.C.)	Contractual services	Work shop	POL	Non Recurring Contingencies (N.R.C.)	Institutional Charges	Total
0.750	0.00	2.000	4.97	0.000	0.200	3.000	0.00	10.92

Total Amount Spent in 2008-09

Traveling Allowances	OTA	Recurring Contingencies (R.C.)	Contractual services	Work shop	POL	Non Recurring Contingencies (N.R.C.)	Institutional Charges	Total
0.32	0.0	0.00	1.62	0.00	0.0	1.94	0.00	1.94

ICAR Research Complex for Eastern Region, Patna

Budget allocation for 2008-09

Traveling Allowances	OTA	Recurring Contingencies (R.C.)	Contractual services	Work shop	POL	Total (1+2+3 +4+5+6)	Non Recurring Contingencies (N.R.C.)	Institutional Charges	Total
0.0721	0.05	0.51159	3.88527	0	0.2	4.71897	5.00	0.0	9.71897

Total Amount Spent in 2008-09

Traveling Allowances	OTA	Recurring Contingencies (R.C.)	Contractual services	Work shop	POL	Total (1+2+3 +4+5+6)	Non Recurring Contingencies (N.R.C.)	Institutional Charges	Total
0.75	0.05*	3.00	8.97	0.00	0.20	12.97	5.00	1.80*	19.77

* We have received 17.92 lakhs except OTA and Institutional charge amounting to 1.85 lakhs

National Dairy Research Institute, Karnal

Budget allocation for 2008-09

Traveling Allowances	OTA	R.C	Contractual Services	NRC	Institutional Charges	Vehicle/ POL	Total

Total Amount Spent in 2008-09

Traveling Allowances	OTA	R.C	Contractual Services	NRC	Institutional Charges	Vehicle/ POL	Total

Central Marine Fisheries Research Institute, Cochin

Budget allocation for 2008-09 (in lakhs)

Trav-eling Allow-ances	OTA	Recur-ring Con-tingencies (R.C.)	Con-tractual services	Work shop	POL	Total (1+2+3 +4+5+6)	Non Recur-ring Con-tingencies (N.R.C.)	Institu-tional Charg-es	Total
0.75	-	4.00	9.94	-	0.20	14.89	6.00	-	20.89

Total Amount Spent: (April,08 to March, 09): **Rs. 13,53,036**
Balance amount as on 31st March, 2009(including unspent balance for the year 2007-08)

Total Amount Spent in 2008-09 (in Rupees)

Trav-eling Allow-ances	OTA	Recur-ring Con-tingencies (R.C.)	Con-tractual services	Work shop	POL	Total (1+2+3 +4+5+6)	Non Recur-ring Con-tingencies (N.R.C.)	Institu-tional Charg-es	Total
9478	-	99950	556130	-	9841	675399	1200000	-	1875399

Central Inland Fisheries Research Institute, Barrackpore

Budget allocation for 2008-09

Trav-eling Allow-ances	OTA	Recur-ring Con-tingencies (R.C.)	Con-tractual services	Work shop	POL	Total (1+2+3 +4+5+6)	Non Recur-ring Con-tingencies (N.R.C.)	Institu-tional Charg-es	Total
0.75	0.0	3.00	4.97	0.0	0.2	8.92	4.00	0.0	12.92

Total Amount Spent: (April, 08 to March, 09): Rs. 8.94

Total Amount Spent in 2008-09

Trav-eling Allow-ances	OTA	Recur-ring Con-tingencies (R.C.)	Con-tractual services	Work shop	POL	Total (1+2+3 +4+5+6)	Non Recur-ring Con-tingencies (N.R.C.)	Institu-tional Charg-es	Total
0.31	0.0	2.39	0.61	0.0	0.2	2.29	1.69	0.0	3.98

Tamil Nadu Agricultural University, Coimbatore

Budget allocation for 2008-09 (in lakhs)

Traveling Allowances	OTA	Recurring Contingencies (R.C.)	Contractual services	Work shop	POL	Total (1+2+3 +4+5+6)	Non Recurring Contingencies (N.R.C.)	Institutional Charges	Total
0.75	-	4.00	9.94	0.05	0.20	15.39	5.50	-	20.89

Total Amount Spent: (April, 08 to March, 09): Rs. 14, 29,687
Closing Balance as on 31.03.08 = Rs. 11,09,484
Closing Balance as on 31.03.09 = Rs. 6, 59,313
Balance amount as on 31st March, 2009: Rs. 6, 59,313+11,09,484 = Rs. 17,68,797

Total Amount Spent in 2008-09 (in rupees)

Traveling Allowances	OTA	Recurring Contingencies (R.C.)	Contractual services	Work shop	POL	Total (1+2+3 +4+5+6)	Non Recurring Contingencies (N.R.C.)	Institutional Charges	Total
71,197	-	3,45,972	6,96,471	43,932	-	11,57,572	2,72,115	-	14,29,687

Publications

Papers published

Indian Agricultural Research Institute, New Delhi

1. S. Singh and P.K. Aggarwal and R.N. Yadav (2008). Warming effect on growth, yield and carbohydrate/nitrogen levels in shoots of wheat cultivars. Indian J. Plant Physiology.

2. S. Singh, Mishra, Kalpana, K. (2008). Genetic diversity for grain yield and nutritional traits in rice (*Oryza sativa*, L.). IRRN, Los Banos Laguna, Philippines.

3. S. Singh, P.K. Aggarwal and B. Chakrawaorti (2008). Assessing the impact of elevated temperature and CO2 on crop growth and yield. Research Bulletin of NPCC, ICAR (In press).

4. Chaudhary A., Manjaiah K.M., Singh R.K and. Aggarwal, P.K. (2009). Impact of Climate Change (warming) on Microbial Diversity. Research Bulletin of NPCC, ICAR (In Press).

5. S. Singh and A. Chaudhary (2008). Manual of Winter School on Climate change, Crop yield and sustainability held from 15th Feb.-7th March 2008.

6. S. Singh, R. Harit and V. Kumar (2008). Growth and yield sensitivity of wheat cultivars to heat stress under late sown conditions. Presented in Golden Jubilee National Seminar on Plant Physiology held at IARI, New Delhi from 11-13 Nov., 2008.

7. S. Singh, R. Harit and V. Kumar (2009). Impact of rising temperature on crop yield. Presented in National Seminar on Climate change organized by the Ministry of Earth at CGO Complex, Lodhi Road New Delhi on 27th Jan, 2009.

8. S. Singh, R. and Shiv Prasad (2009). Impact of Climate change on loss of biodiversity. Presented in National Seminar on Climate change organized by the Ministry of Earth at CGO Complex, Lodhi Road New Delhi on 27th Jan, 2009.

Central Research Institute for Dryland Agriculture, Hyderabad

1. Rao, G.G.S.N., Rao, A.V.M.S. and Rao, V.U.M. 2008. Climate change and its impacts on various sectors. *Proceedings of the National Seminar on Climate Changes – Its impact on different sectors in India*. July 30 –31, 2008. VSR & NVR College, Tenali. p. 1-7.

2. Rao, V.U.M., Rao, G.G.S.N., Rao, A.V.M.S., Satyanarayana, T. and Manikandan, N. 2008. Climate risk management through weather insurance. *Proceedings of the National Seminar on Climate Changes – Its impact on different sectors in India*. July 30 –31, 2008. VSR & NVR College, Tenali. p. 21-30.

3. Rao, G.G.S.N., Rao, V.U.M. and Rao, A.V.M.S. 2008. Climate change and its impact on agriculture. *Proceedings of the International Workshop on Weather Modification Technologies & Symposium on Natural Disaster Management.* June 27-29, 2008. Jawaharlal Nehru Technological University, Hyderabad.

4. Rao, A.V.M.S., Manikandan, N., Satyanarayana, T., Rao, V.U.M. and Rao, G.G.S.N. 2008. Decadal shifts in monthly rainfall and annual drought pattern in different agro-climatic zones of Andhra Pradesh. *Proceedings of the International Workshop on Weather Modification Technologies & Symposium on Natural Disaster Management.* June 27-29, 2008. Jawaharlal Nehru Technological University, Hyderabad.

5. M. Vanaja, M. Jyothi, P. Ratnakumar, P. Vagheera, P. Raghuram Reddy, N. Jyothi lakshmi, S.K.Yadav, M. Maheshwari and B. Venkateswarlu. 2008. Growth and yield responses of castor bean (*Ricinus communis* L.) at two enhanced CO_2 levels. *Plant Soil and Environment* 54 (2): 38-46.

6. M. Vanaja, M. Maheswari, P. Raghu Ram Reddy, N. Jyothi Lakshmi, S.K. Yadav. 2008. Response of Rainfed Crops to Elevated CO_2 at Normal and Drought Conditions. Golden Jubilee Conference on 'Challenges and Emerging Strategies for Improving Plant Productivity' from 12th to 14th November 2008 at IARI, New Delhi.

7. M. Srinivasa Rao, K. Srinivas, M. Vanaja, GGSN Rao, B Venkateswarlu and Y S Ramakrishna, 2009 Host mediated effect of elevated CO_2 on lepidopteron Insect pests of castor (*Ricinus communis* Linn) communicated to Current science journal.

8. M. Vanaja, M. Jyothi, P. Ratnakumar, P. Vagheera, P. Raghuram Reddy, N. Jyothi Lakshmi, S.K.Yadav, M. Maheshwari and B. Venkateswarlu. 2008. Growth and yield responses of castor bean (*Ricinus communis* L.) at two enhanced CO_2 levels. *Plant Soil and Environment* 54 (2): 38-46.

Research bulletin

1. **Srinivasa Rao, M.**, Srinivas, K., Vanaja M, Rao GGSN and Venkateswarlu B. 2008 Impact of elevated CO_2 on insect herbivore–host interactions. *Research Bulletin*. pp36.

Central Plantation Crops Research institute, Kasargod

1. Naresh Kumar, S., Kasturi Bai, K.V. Rajagopal V. and Aggarwal, P.K. 2008. Simulating coconut growth, development and yield using InfoCrop-coconut model. Tree Physiology (Canada)- 28: 1049–1058.

2. Naresh Kumar, S., M.S. Rajeev and Vinayan D.D. Nagvekar, R. Venkitaswamy, D.V. Raghava Rao, B. Boraiah, , M. S.Gawankar, R. Dhanapal, D.V. Patil and K.V. Kasturi Bai. 2007. Trends in weather and yield changes in past in coconut growing areas in India. Oral presentation at National Conference on "*Impact of Climate Change with Paricular Reference to Agriculture*" at TNAU, Coimbatore from 22-24, August, 2007.

3. Naresh Kumar, S. K.V. Kasturi Bai and John George. 2008. A method for non-destructive estimation of dry weight of coconut stem. J. Plantn. Crops. 36(3): 296-299.

4. Naresh Kumar, S., Rajagopal V., Cherian V.K., Siju Thomas T., Sreenivasulu B., Nagvekar D.D., Hanumanthappa M., Bhaskaran R., Vijaya Kumar K., Ratheesh Narayanan M.K. and Amarnath C.H. (2009). Weather data based descriptive models for prediction of coconut yield in different agro-climatic zones of India. Indian J. Hort. 66 (1): 88-94.

5. Naresh Kumar, S., K.V. Kasturi Bai and G.V. Thomas. 2008. Climate change and plantation crops. In: Impact assessment of climate change for research priority planning in horticultural crops. Eds. SS Lal, PM Govindakrishnan, VK Dua, JP Singh and SK Pandey. CPRI Publication. Pp. 67-80.

6. Naresh Kumar, S. 2008. http://www.livemint.com/2008/06/13003015/Global-warming-to-raise-coconu.html.

ICAR Research Complex for Eastern Region, Patna

1. Adlul Islam, Alok K Sikka and S Prasad (2007). Investigation of streamflow trend in Brahmani Basin. Hydrological Sciences Journal (Paper No: 2978).

2. Islam, A., A. K Sikka, B. Saha, and Anamika (2007). Application of GIS and Image Processing in Distributed Hydrological Modeling. *Institute Bulletin (Bulletin No*: R-26/PAT-15*)*.

3. Estimation of climate change impact on rice yield (var.Sita) in Bihar (2008). A. Abdul Haris, R. Elanchezhian, A.K. Sikka, Vandna Chhabra, Arvind Pratap and Sandeep Biswas. (*accepted for Bihar Science Congress,2008*).

4. Impact of climate change on wheat and maize yield at Pusa in Bihar (2008). A. Abdul Haris, A.K. Sikka, R. Elanchezhian, Sandeep Biswas, Vandna Chhabra and Arvind Pratap. (*accepted for Bihar Science Congress,2008*).

5. Sensitivity of crop yield to temperature under different CO_2 scenarios through Infocrop model. (2008). A. Abdul Haris, R. Elanchezhian, R.K. Batta, Vandna Chhabra, Sandeep Biswas and Arvind Pratap. (*accepted for Bihar Science Congress,2008*).

Central Marine Fisheries Research Institute, Cochin

1. Vivekanandan, E., N.G.K. Pillai and M. Rajagopalan. 2008. Adaptation of the oil sardine *Sardinella longiceps* to seawater warming along the Indian coast. In: Glimpses of Aquatic Biodiversity, Rajiv Gandhi Chair Spl. Publ., 111-119.

2. Vivekanandan, E. and J. Jayasankar. 2008. Impact of climate change on Indian marine fisheries. Proc. Winter School, CMFRI, Cochin, 302 pp.

Participation in seminars

i. Conducted ICAR sponsored Winter School “Impact of Climate Change on India Marine Fisheries” for 22 participants from Universities, colleges and ICAR Institutions for 21 days from 18.1.2008 to 7.2.2008 at CMFRI, Cochin.

ii. Participated in the National Conference on climate change and made a presentation at NASC Complex, New Delhi on October 12 & 13, 2007.

iii. Participated and presented a paper on Climate Change organized by Press Club of India on October 24, 2007 at Cochin.

iv. Participated and presented a paper "Issues in vulnerability assessment and adaptation in India" in the workshop organized by NATCOM Project Management Cell of MoE&F, Government of India on November 1 & 2, 2007 at New Delhi.

v. Participated and presented a paper "Environmental Issues and Capture Fisheries Sustainability" in the workshop organized by Cochin University on November, 16, 2007 at Cochin.

vi. Participated and presented a paper "Climate change impacts in fisheries in Kerala" orgainsed by Kerala Agricultural University at Fisheries College, Panangad on December 14, 2007.

vii. Participated and presented a paper Climate Change and Food Security with special reference to Marine Fisheries in the International Symposium conducted at CRIDA on February 18 & 19, 2008 at Hyderabad.

Tamilnadu Agricultural Reserch Institute, TNAU

1. Palanisami, K., P. Paramasivam, C.R. Ranganathan P.K. Aggarwal, and S.Senthilnathan, 2009. "Quantifying Vulnerability and Impact of Climate Change on Production of Major Crops in Tamil Nadu, India", From Headwaters to the Ocean-Hydrological changes and Watershed Management, Taylor & Francis Group, London, U.K, ISBN 978-0-415-47279-1 pp 509-514.

2. Palanisami, K., P.K. Aggarwal, S. Natarajan, C.R. Ranganathan, R. Sivasamy, P. Paramasivam, V. Geethalakshmi and S. Senthilnathan, 2007. "Quantifying the Impact of Climate Change on Production of Major Crops in Tamil Nadu", CARDS Series 30, Pp 49.

3. Palanisami. K, C. Ranganathan, S. Senthilnathan and Chieko Umetsu, 2008. "Developing the Composite Vulnerability Index relating to Climate Change for the Different Agro Climatic Zones of Tamil Nadu", Inter-University Research Institute Corporation, National Institutes for the Humanities, Research Institute for Humanity and Nature, Japan, Pp 127-137. ISBN: 978-4-902325-28-7.

4. V. Geethalakshmi, S. Kokilavani, R. Nagarajan, C. Babu and S. Poornima. 2008. Impacts of Climate Change on rice and ascertaining adaptation opportunities for Tamil Nadu state. In the proceedings of the International symposium on Agrometeorology and Food security conducted by CRIDA, Hyderabad between 18 – 21, February, 2008 : pp: 21 - 22.

5. V. Geethalakshmi and Ga. Dheebakaran. 2008. Impact of climate change on agriculture over Tamil Nadu. In: Climate Change and Agriculture over India. Published by AICRP on Agrometeorology. Pp: 79 – 93.

6. V. Geethalakshmi, S. Kokilavani, R. Nagarajan, C. Babu and S. Poornima. 2008. Impacts of Climate Change on rice and ascertaining adaptation opportunities for Tamil Nadu state. In the

proceedings of the International symposium on Agrometeorology and Food security conducted by CRIDA, Hyderabad between 18 – 21, February, 2008: pp: 21 - 22.

National Dairy Research Institute, Karnal

1. R.C. Upadhyay. Climate Change Impacts-Livestock and their management. In, Training programme on Capacity building of Scientists of AICRPAM and AICRPDA on Impact of climate change in Indian Agriculture, 25-26 June, 2008, CRIDA, Hyderabad
2. S.V. Singh, R.C. Upadhyay and Ashutosh (2008) Climate change and its impact on bovine productivity. In: Compendium of lectures-CAS short course on "Recent Development in Animal Production and Reproduction" held at IVRI, Izatnagar-132001. pp. 48-51.
3. R.C. Upadhyay. Climate change – Impact on Indian Livestock. In, Interactive workshop on Climate Change and Indian livestock, NDRI, Karnal, September 20-21, 2008.
4. R.C. Upadhyay. Climate Change and Indian Livestock: An Overview, In, National Seminar on Emerging opportunities for commercialization in Dairying, NDRI and Alumni Association, NDRI, Karnal, November 6-7, 2008, pp 93- 105 (Invited presentation).
5. R.C.Upadhyay. Impact of climate change on milk production and availability in India, In, International Conference on Combating Climate Change, February 7-8, 2009, Vigyan Bhavan, New Delhi, pp 50-51 (Invited presentation).
6. R.C. Upadhyay. Resilience in Indian livestock biodiversity to withstand climate change. In, National Symposium on Livestock biodiversity conservation & Utilization: Lessons from past and future perspectives, February 12-13, 2009, NBAGR, Karnal, pp 97-107 (Invited presentation).
7. R.C. Upadhyay, Ashutosh, Parva Mayengbam, Singh, S.V. and Rita (2009) Climate change and long-term impacts on animal functions and production. In: Compendium XVIII Annual Conference of SAPI on "Physiological Prospects in Augmenting Livestock Production" organized by NIAN&P, Bangalore from Feb. 26-28 2009. pp. 133-139. (Invited presentation).

Indian Institute of Horticultural Research Institute, Bangalore

1. N.K. Srinivasa Rao, R.H. Laxman and R.M. Bhatt (2008). "Potential impacts of climate change on vegetable crops". In: Impact assessment of climate change for research priority planning in horticultural crops. Eds S.S. Lal, P.M. Govindakrishnan, V.K. Dua. J.P. Singh and S.K. Pandey, CPRI, Shimla, pp 137-144.
2. Laxman, R.H., Shivashankara, K.S. and Srinivasa Rao, N.K. (2008). "Climate change: Potential impacts on fruit crops". In: Impact assessment of climate change for research priority planning in horticultural crops. Eds S.S. Lal, P.M. Govindakrishnan, V.K. Dua. J.P. Singh and S.K. Pandey, CPRI, Shimla, pp 47-59.

Coordinating Center

Indian Agricultural Research Institute

New Delhi

Collaborating Centers

- **Central Research Institute for Dryland Agriculture,** Hyderabad
- **Central Plantation Crops Research Institute,** Kasaragod
- **Indian Institute of Horticultural Research,** Bangaluru
- **CSK Himachal Pradesh Agricultural University,** Palampur
- **Central Soil and Water Conservation Research and Training Institute,** Dehradun
- **ICAR Research Complex for Eastern Region,** Patna
- **National Dairy Research Institute,** Karnal
- **Central Marine Fisheries Research Institute,** Cochin
- **Central Inland Fisheries Research Institute,** Barrackpore
- **Tamil Nadu Agricultural University,** Coimbatore

For further details contact :

Dr. P.K. Aggarwal
ICAR National Professor
pkaggarwal.iari@gmail.com

Dr. G.G.S.N. Rao
Project Coordinator (Agromet)&NPCC (F)
Email: ggsnrao@yahoo.co.in

Dr. B. Venkateswarlu
Director
Email: vbandi_1953@yahoo.com

Central Research Institute for Dryland Agriculture (CRIDA)
Santoshnagar, Hyderabad 500059
Website: www.crida.ernet.in
Phone: 040-24530177 Fax: 040-24531802 E mail: Climatechange.crida@gmail.com