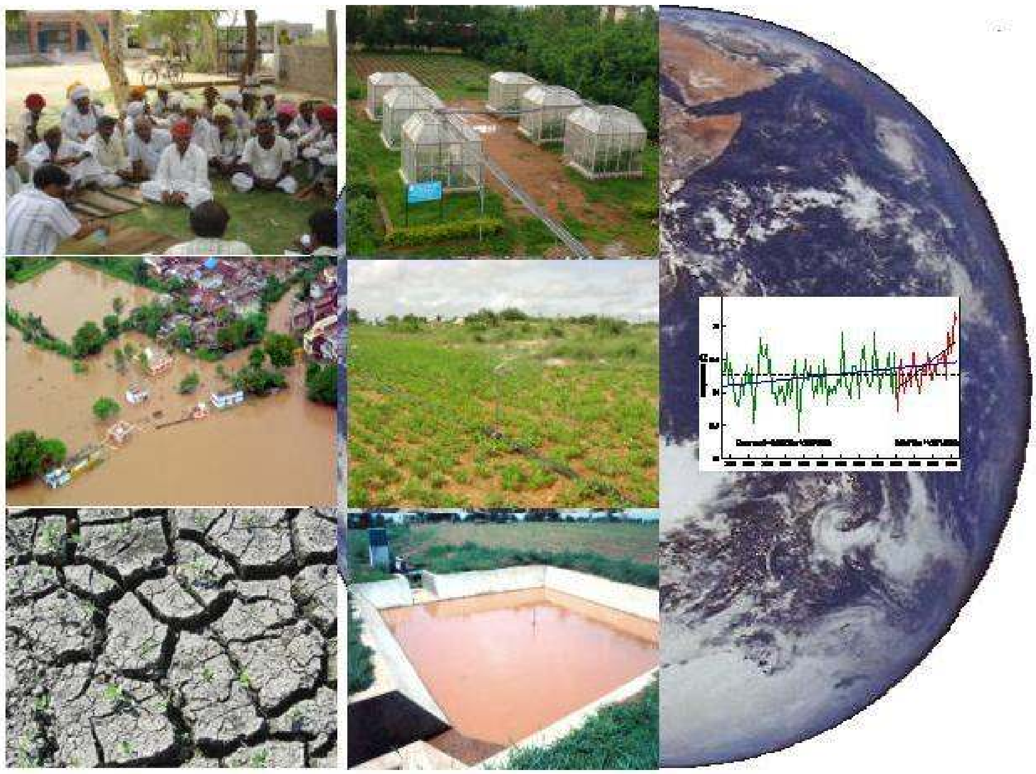
# Network Project on Climate Change
# Consolidated Annual Report (2004 - 2007)



## Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change

**Central Research Institute for Dryland Agriculture**
**Santoshnagar, Saidabad (PO)**
**Hyderabad – 500 059 Andhra Pradesh**

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## *ICAR Network Project*

**on**

# Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change

**Final Report of the first phase**
**2004-07**

Coordinating Centre

**Indian Agricultural Research Institute**

Collaborating Centres
Central Plantation Crop Research Institute, Kasaragod
Central Research Institute for Dryland Agriculture, Hyderabad
Jawahar Lal Nehru Krishi Vishwavidyalaya, Jabalpur
Indian Institute of Horticultural Research, Bangalore
CSK Himachal Pradesh Agricultural University, Palampur
University of Horticulture and Forestry, Solan
Indian Institute of Soil Science, Bhopal
Central Soil & Water Conservation Res and Training Inst, 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
Narendra Dev University of Agriculture and Technology, Faizabad

# INDEX

**Coordinating Institute**: **Indian Agricultural Research Institute, New Delhi-110012**
**Dept./ Div. Name and address: Division of Environmental Sciences**

**Principal Investigator:**
Dr. P. K. Aggarwal, National Professor

**Co-Investigators:** Annexure 1

**Names of Research Associates / Senior Research Fellows**: Annexure 2

**Duration of scheme:** Till $10^{th}$ plan (March 2007)

**Total cost of the scheme:** 910.87 lakhs

**Budget allocation and expenditure:** Annexure 3

**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 ńno regretsô 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
To provide policy support for the international negotiations on global climatic changes.

**Detailed objectives of different institutes:** Annexure 4

**Executive summary of the report:** Annexure 5 for Center wise summaries

1. Simulation studies indicate a possibility of loss of 4-5 million tons in wheat production with every rise of $1^{o}C$ temperature throughout the growing period even after considering carbon fertilization (but no adaptation benefits. Simple adaptations such as change in planting dates and crop varieties could reduce these losses to 1-2 million tons.
2. Changes in climate are expected to create both positive as well as negative impacts on rice yield of Tamil Nadu. Impact is more during Kharif season (Southwest monsoon) than in Rabi (Northeast monsoon) season. During Kharif season in 2020, 10 to 15 per cent reduction in rice yield is expected due to increase in temperature and change in rainfall. In 2050, 30 to 35 percent yield reduction and in 2080, up to 80 percent yield reduction is expected in Tamilandu.
3. Ricardian approach was used to analyse the impact of climate change using cross section and time series data for the Tamilnadu state. Paddy is projected to decrease both in terms of area and productivity, resulting in lower production levels of about 13 percent in 2050 and 9 percent in 2020 from existing levels. Sugarcane is projected to decrease by 9.45 and 13.4 percent in terms of area and productivity in short term and about 13 and 9 percent in terms of area and productivity in the long term. Area under groundnut is projected to decrease by 5.12 and 3.65 percent in medium and

long term. Groundnut yields are projected to decline by a 7.04 percent in medium term and by 5.36 percent in long term.

4. Analysis of recent weather data in Himachal Pradesh indicated that the maximum temperature is showing an increasing trend during November to April. This has resulted in a possible shift of apple belt upwards (and thus limited fulfillment of chilling hour❛s requirements of the crop) and increasing area of apple in higher elevations. The new areas of apple cultivation have appeared in Lahaul and Spitti and upper reaches of Kinnaur district of Himachal Pradesh. Trend predicted apple productivity in Kullu, Shimla as well as overall average productivity of the state has shown declining trend. Average state productivity in 1980 -81 was 7.06 tons $ha^{-1}$ that decreased to 4.65 tons $ha^{-1}$ in 2004-05

5. Coconut yields are likely to be affected by global climate change. Plains of Karnataka, Eastern TN, coastal AP, Pondicherry, WB and Assam were found to be hot spots as per HadCM3 model scenarios of climate change; No change in productivity was projected due to climate change in coastal Karnataka and Kerala.
6. Global warming is likely to lead to a loss of 1.6 million tones in milk production by 2020 and 15 million tones by 2050. High producing crossbred cows and buffaloes will be affected more by climate change. Based on temerature-humdity index (THI), the estimated annual loss in milk production at the all-India level is 1.8 million tones by 2020(valued at rs.2661.62 crores at current prices). The economic losses were highest in UP followed by Tamil Nadu, Rajasthan and W.Bengal.
7. A rise of 2-6 °C due to global warming (time slices 2040-2069 and 2070-2099) will negatively impact growth, puberty and maturity of crossbreds and buffaloes and time to attain puberty of crossbreds and buffaloes will increase by one to two weeks due to their higher sensitivity to temperature than indigenous cattle.
8. A rise in temperature as small as 1°C could have important and rapid effects on the mortality of fish and their geographical distributions. Oil sardine fishery did not exist before 1976 in the northern latitudes and along the east coast as the resource was not available/and sea surface temperature (SST) were not congenial. With warming of sea surface, the oil sardine is able to find temperature to its preference especially in the northern latitudes and eastern longitudes, thereby extending the distributional boundaries and establishing fisheries in larger coastal areas.
9. The dominant demersal fish, the threadfin breams have responded to increase in SST by shifting the spawning season off Chennai. Whereas 35.3% of the spawners of *Nemipterus japonicus* occurred during the warm months (April-September) in 1980, the number of spawners gradually reduced and only 5.0% of the spawners occurred during the same season in 2004. During this period, the spawning activity reduced in summer months and shifted towards cooler months. A similar trend was observed in *Nemipterus mesoprion* too.
10. Corals in Indian Ocean will be soon exposed to summer temperatures that will exceed the thermal thresholds observed over the last 20 years. Annual bleaching of corals will become almost a certainty from 2050. Given the implication that reefs will not be able to sustain catastrophic events more than 3 times a decade, reef building corals are likely to start disappear as dominant organisms on coral reefs between 2030 and 2040 and the reefs are likely to become remnant between 2050 and 2060 in the Gulf of Mannar.

11. Recent climatic patterns have brought about hydrological changes in the flow pattern of river Ganga. This has been one major factor resulting in erratic breeding and decline in fish spawn availability. As a result the total average fish landing in the

Ganga river system declined from 85.21 tones during 1959 to 62.48 tones during 2004. In the middle and lower Ganga sixty genera of phytoplankton was recorded during 1959 and declined to 44 numbers by 1996. In case of Zooplankton during the same period the number diminished from 38 to 26. A number of fish species, which were predominantly only available in the lower and middle Ganga in 1950s, are now recorded from the upper cold-water stretch upto Tehri.

12. In recent years the phenomenon of Indian Major Carps maturing and spawning as early as March is observed in West Bengal with its breeding season extending from 110-120 days (Pre1980-85) to 160-170 days (2000-2005). As a result it has been possible to breed them twice in a year at an interval ranging from 30-60 days. A prime factor influencing this trend is elevated temperature, which stimulate the endocrine glands and help in the maturation of the gonads of Indian major carp. The average minimum and maximum temperature throughout the state has increased in the range of 0.1 to 0.9ºC.
13. High temperature around flowering increased pollen sterility in rice and reduced pollen germination on stigma. Aromatic rice was more sensitive than non-aromatic rice. High temperature also reduced test weight, grain elongation and aroma in basmati rice.
14. Two generations of castor crop showed significant response under elevated $CO_2$ levels (700 & 550 ppm) in terms of growth, biomass and yield. The growth characters *viz*., root and shoot lengths, root shoot ratios, leaf area, root, stem, and leaf dry weights and specific leaf area were fund to be significant at higher at 550 and 700ppm $CO_2$ in both the generations.
15. The impact of elevated $CO_2$ on relative growth rates of castor insect was strongly influenced by both host mediated factor (elevated $CO_2$) and direct effect of $CO_2$ and temperature decreasing in larvae fed castor. High $CO_2$ foliage was 8 % more digestible for insect larvae than ambient $CO_2$ foliage. Larvae were, however, much less efficient in converting digested castor in to body mass. Results indicated that the predicted pest incidence would be low during (2020) and moderate during 2050 and 2080 years of Hyderabad area.
16. Pest prediction equations in relation to temperature were developed for thrips population in horticultural crops. It was observed that thrips on rose required 265 and aphids 119 thermal day degrees (TDD) for development under field conditions.
17. In future, soil conservation efforts would need greater focus in Peninsular and central India because of their projected high runoff and soil losses associated with global climate change. A decreasing trend of runoff and soil loss is ordered when we move from tropics to temperate region.
18. Simulation results indicated an increase in mean annual streamflow at several places in 2020 and 2050 under PRECIS RCM scenarios. Though there is increase in annual streamflow, a decrease in monthly streamflow, particularly during summer months (February ï June) was projected.
19. An inventory of enteric methane emission for 2006 was prepared following IPCC guidelines on good practice guidance and uncertainty reduction and using Tier 2 methodology of IPCC. Tier 1 methodology and default factors of IPCC have been used for estimating enteric methane emissions for Sheep, Goats, equines, Pigs and other animals. The emissions for the year 2006 were estimated at 9.39 Tg/annum from both enteric emissions and manure management. The contribution of indigenous cattle to enteric emission was 38% and that of buffaloes 43%.
20. Inventory of greenhouse gases emissions from rice and wheat production systems was developed for all India based on InfoCrop model. It indicated higher emissions in

intensely cultivated regions of Indo-Gangetic plains, coastal Andhra Pradesh & Orissa. No tillage mitigated emissions to a limited extent in upland cropping.

21. Annual C sequestration in coconut above ground biomass varies from 15 CERs to 35 CERs depending on cultivar, agro-climatic zone, soil type and management; Annually sequestered carbon stocked in to stem in the range of 0. 3 to 2.3 CERs; Standing C stocks in 16 year old coconut cultivars in different agro-climatic zones varied from 15 CERS to 60 CERs; Annual C sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils
22. Agroforestry has maximum carbon sequestration potential in subtropical climate and the least in dry temperate. Its carbon sequestration potential decreased with the increase in altitudinal gradient from 468 m asl ï 2100 m asl. Agri-silviculture (*Toona ciliata* + Maize - Wheat) and agri- horti-silviculture (*Mangifera indica* + *Toona ciliate* + Maize - Wheat) are the most suitable agroforestry systems to be used in for carbon sequestration in subtropical climate type. Agri-horticulture has been the most suitable system for carbon sequestration in temperate climate among the four climate types. Apple+ Pea followed by Apple + Cabbage- Frenchbean formed the best combinations.
23. Regional climatic zonewise carbon inventory of agroforestry systems of Himachal Pradesh based on revised 1996 IPCC Guidelines for National Greenhouse Gas Inventory has been prepared. The agroforestry systems inventories were agri-silviculture, agri-horti-silviculture, agri-horticulture and silvi-pasture systems under the business as usual scenario i.e. current management scenario agri-silviculture and silvi-pasture systems were evaluated to contribute positively towards carbon sequestration whereas agri-horticulture and agri-horti-silviculture systems were found to release more carbon to the atmosphere.

**Detailed Progress report**: Annexure 6

**Papers Published:** Annexure 7

**Signature of the Principal Investigator**

Name: PK Aggarwal
Designation: National professor and Network Coordinator (Climate Change)

**Remarks of the Council:**

**ANNEXURE 1: Co-Investigators:**

**Indian Agricultural Research Institute**

- **Name : Dr. Santha Nagarajan , Principal Investigator**
  **Designation : Principal Scientist, Nuclear Research Laboratory**
- Name : Dr. P.K. Aggarwal
  Designation : Head, Division of Environmental Sciences
- Name : Dr. R. Choudhary,
  Designation : Principal Scientist
- Name : Dr. S.D. Singh
  Designation : Senior Scientist
- Name : Dr. Anita Choudhary
  Designation : Senior Scientist
- Name : Dr. Arti Bhatia
  Designation : Scientist Senior Scale
- Name : Dr. K.M. Manjaiah
  Designation : Senior Scientist
- Name : Dr. Anjali Anand
  Designation : Scientist Senior Scale
- Name : Dr. H.B. Choudhary
  Designation : Principal Scientist
- Name : Dr. a. S. Hari Prasad
  Designation : Scientist Senior Scale
- Name : Dr. Madan Pal
  Designation : Senior Scientist
- Name : Dr. V. K. Sehgal
  Designation : Senior Scientist
- Name : Dr. D. Chakraborty
  Designation : Scientist
- Name : Dr. B. Banerjee
  Designation : Scientist

**Central Plantation Crop Research Institute, KASARAGOD**

- **Name : Dr. S. Naresh Kumar (Principal Investigator)**
  **Designation : Senior Scientist (Plant Physiology)** :
- Name : Dr. K.V. Kasturi Bai
  Designation : Principal Scientist and Acting HD
- Name : Dr. C. Palnaiswamy
  Designation : Senior Scientist
- Name : Dr. C. V. Sairam
  Designation : Senior Scientist
  ***(Dr C.T Jose (Senior Scientist-Statistics) replaced Dr. C.V. Sairam as the later went on transfer in February, 2006)***
- Name : Dr. K.S. Krishnamurthy
  Designation : Senior Scientist
- Name : Dr. B. Champakam
  Designation : Principal Scientist and HD, Crop production

- Name : Dr. Kandiannan
  Designation : Senior Scientist

**Central Research Institute for Dryland Agriculture, HYDERABAD**

- **Name : Dr. GGSN Rao (Principal Investigator)**
- **Designation : Project Coordinator**
- Name : Dr. M. Vanaja
- Designation : Senior Scientist (Pl. Physiology)
- Name : Dr. J. V. N. S. Prasad
- Designation : Senior Scientist (Ag. Forestry)
- Name : Dr. M. Srinivasa Rao
- Designation : Senior Scientist (Ag. Ent.)
- Name : Dr. Y. S. Ramakrishna
- Designation : Director
- Name : Mr. A.V.M. Subba Rao
- Designation : Scientist (Agromet.)
- Name : Dr. K. P. R. Vittal
- Designation : Project Coordinator (Dryland)
- Name : Dr. K. V. Rao
- Designation : Senior Scientist (Ag. Engg.)
- Name : Dr. G. Ravindrachary
- Designation : Senior Scientist (Agronomy)
- Name : Dr. M. Maheswari
- Designation : Senior Scientist (Pl. Physiology)
- Name : Dr. P. Raghuram Reddy
- Designation : Principal Scientist (Plant Breeding)
- Name : Dr. S. K. Yadav
- Designation : Senior Scientist (Biochemistry)
- Name : Dr. N. Jyothi Laxmi
- Designation : Scientist Sr. Scale (Pl. Physiology)
- Name : Dr. B. Venkateswarlu
- Designation : Principal Scientist (Microbiology)
- Name : Dr. G. Subba Reddy
- Designation : Principal Scientist (Agronomy)
- Name : Dr. K. Srinivas
- Designation : Scientist (Soil Science)
- Name : Dr. Y. G. Prasad
- Designation : Senior Scientist (Entomology)
- Name : Dr. M. Pravakar
- Designation : Senior Scientist

**Jawahar Lal Nehru Krishi Vishwavidyalaya, Jabalpur**

- **Name : Dr. S.D. . Upadhyaya, Principal Investigator**
  **Professor (Plant Physiology)**
  Designation : Sr. Scientist, Plant Breeding and Genetics
- Name : Dr. V. K. Gour
  Designation : Sr. Scientist, Plant Breeding and Genetics
- Name : Dr. A.P. Upadhyaya
  Designation : Sr. Scientist, Agronomy and Agrometeorology
- Name :Dr. S.B. Nahatkar
  Designation : Sr. Scientist, Agricultural Economics

**Indian Institute of Horticultural Research, BANGALORE**

- **Name : Dr. N.K. Srinivasa Rao, Principal Investigator**
  **Designation : Principal Scientist**
- Name : Dr. P.N.Krishna Murthy
  Designation : Principal Scientist
- Name : Dr. A. Verghese
  Designation : Principal Scientist
- Name : Dr. M.Prabhakar,
  Designation : Principal Scientist
- Name : Dr. R.M.Bhatt,
  Designation : Senior Scientist
- Name : Dr. R.H.Laxman,
  Designation : Senior Scientist
- Name : Dr. V. Sridhar
  Designation : Scientist (SS)
- Name : Dr. R.Venugopalan,
  Designation : Scientist (SS)

**CSK Himachal Pradesh Agricultural University, PALAMPUR**

- **Name : Dr. R.M. Bhagat, Principal Investigator**
  **Designation : Professor, Programme Director**
- Name : Dr. Rajendra Prasad
  Designation : Agro meteorologist, Department of agronomy.
- Name : Dr. Ranbir Singh Rana
  Designation :Ass. Scientist (Agronomy) Center for Geo-informatics Research and Training
- Name : Dr. Harbans Lal
  Designation : Assistant Scientist (Agril Econ.)
- Name : Dr. Chitra Sood
  Designation :Project Scientist (WOS-I) Center for Geo-informatics Research and Training
- Name : Mr. Vaibhav Kalia
  Designation :Assist. Scientist (Computer applications) Center for Geo-informatics Research and Training.

**University of Horticulture and Forestry, - Solan**

- **Name : Dr. Dr. K.S. Verma, Principal Investigator**
- **Designation : Research Officer (Agroforestry)**
- Name : Dr. M.S. Mankotia
  Designation : Scientist (Horticulture)
- Name : Dr. D.R Bhardwaj
  Designation : Assistant Scientist (Agronomy)
- Name : Dr. S.K. Bhardwaj
  Designation : Assistant Professor (Soil Science)
- Name : Dr. C.L. Thakur
  Designation : Assistant Scientist (Agroforestry)
- Name : Dr. Manoj Thakur
  Designation : Assistant Scientist (Agroforestry)

**Indian Institute of Soil Science, Bhopal**

- **Name : Dr. A. K. Mishra, Principal Investigator**
- **Designation : Principal Scientist**
- Name : Dr. A. K. Biswas
- Designation : Senior scientist
- Name : Dr. M. Mohanty
- Designation : Scientist

**Central Soil and Water Conservation Research and Training Institute, DEHRADUN**

- **Name : Dr. K.P. Tripati, Principal Investigator**
  **Designation :Principal Scientist (Soil & Water Conservation Engineering)**
- Name : Er. S.S. Shrimali
  Designation : Sr. Scientist (Computer Application in Agriculture)
- Name : Dr. N.K. Sharma
  Designation : Sr. Scientist (Agronomy)
- Name : Dr. S. L. Arva (from Dec, 2005)
  Designation : Agricultural Economics

**ICAR Research Complex for Eastern Region, Patna**

- **Name : Dr. Alok K.Sikka, Principal Investigator**
- **Designation : Director**
- Name : Dr. B Saha
  Designation : Sr. Scientist
- Name : Dr A. Upadhaya
  Designation : Sr. Scientist
- Name : Dr. Abdul Haris A.
  Designation : Sr. Scientist
- Name : Mr. Adlul Islam
  Designation : Scientist (SS)
- Name : Dr. A R Reddy
  Designation : Scientist (Sr. Scale)

**National Dairy Research Institute, KARNAL**

- **Name :Dr R.C Upadhyay, Principal Investigator**
  **Designation : Principal Scientist (Animal Physiology)**
- Name :Dr ( Mrs) Madhu Mohini
  Designation : Principal Scientist, DCN Division
- Name : Dr.V.K.Kansal
  Designation : Principal Scientist, ABC Division
- Name : Dr. S.V.Singh
  Designation : Senior Scientist, DCP Division
- Name : Dr. Ashutosh
  Designation : Scientist SS, DCP Division
- Name : Dr. (Mrs) Smita Sirohi
  Designation : Senior Scientist, DES&M Division
- Name : Dr. Sanjay Kumar
  Designation : Senior Scientist, DCP Division

**Central Marine Fisheries Research Institute, COCHIN**

- **Name : Dr. M. Rajagopaln, Prinipal Investigator**
  **Designation : Principal Scientist & Head of Division Fishery Resources Assessment Division.**
- Name : Dr. M. Srinath
  Designation : Principal Scientist & Head of Division Fishery Resources Assessment Division.
- Name : Dr. N.G.K. Pillai
  Designation : Principal Scientist & Head of Division, Pelagic Fisheries Division.
- Name : Dr. Rani Mary George
  Designation : Principal Scientist & Head of Division, Marine Biodiversity Division.
- Name : Dr. E. Vivekanandan
  Designation : Principal Scientist & Head of Division, Demersal Fisheries Division, Madras RC of Central Marine Fisheries Research Institute, Cochin
- Name : Dr. P. K. Krishnakumar
  Designation : Senior Scientist Fishery Environment & Management Division RC of Central Marine Fisheries Research Institute, Mangalore
- Name : Dr. P. Kaladharan
  Designation : Senior Scientist,Fishery Environment & Management Division.
- Name : Dr. Reeta Jayasankar
  Designation : Senior Scientist, Mariculture Division.
- Name : Sri. K. Vijayakumaran
  Designation : Scientist (SG), Fishery Environment & Management Division RC of Central Marine Fisheries Research Institute, Visakhapatnam

**Central Inland Fisheries Research Institute, BARRACKPORE**

- **Name : Dr. Manas Kumar Das, Prinipal Investigator**
- **Designation : Principal Scientist**
- Name : Dr. Mrinal Mukhopadhyaya
  Designation : Principal Scientist
- Name : Dr. Prasanta Kumar Saha
  Designation : Principal Scientist
- Name : Dr. Pradeep Kumar Katiha
  Designation : Senior Scientist
- Name : Dr. Sanjib Manna
  Designation : Scientist
- Name : Mr. Praveen Maurya
  Designation : Scientist
- Name : Mr. Manoj Pandit Brahmanee
  Designation : Scientist

**Tamil Nadu Agricultural University**

- **Name : Dr. K. Palanisamy, Prinipal Investigator**
  **Designation : Director, Water Technology center**
- Name : Dr.P.Paramasivam
  Designation : Associate Professor, Agricultural Economics
- Name : Dr.S.Natarajan
  Designation : Professor, Remote Sensing Unit
- Name : Dr.R.Sivasamy
  Designation : Professor, Remote Sensing Unit
- Name : Dr. V. Geethalakshmi
  Designation : Professor
- Name : Dr.C.R.Ranganathan
  Designation : Professor, Maths

**Narendra Dev University of Agriculture and Technology, FAIZABAD**

- **Name : Dr. Padmakar Tripathi, Prinipal Investigator**
  **Designation : Professor (Plant physiology)**
- Name : Dr. G.S. Chaturvedi
  Designation : Prof & Head, Deptt. of Crop Physiology
- Name : Dr. D. N. Verma
  Designation : Dean, Veterinary Science
- Name : Dr. A.K. Singh
  Designation : Jr. Agronomist, Deptt. of Agril. Meteorology

**ANNEXURE 2: Research Associates / Senior Research Fellows**

**Indian Agricultural Research Institute (Coordinating Centre).**

| Name | From (date) | To |
|---|---|---|
| Ms. D. N. Swarupa Rani (SRF) | 05-03-2005 | 08-08-2005 |
| Ms. D. N. Swarupa Rani (RA) | 10-08-2005 | 31-03-2007 |
| Dr. Anima Biswal (RA) | 05-03-2005 | 31-03-2007 |
| Dr. Rani Saxena (SRF) | 11-08-2005 | 31-03-2007 |

**Indian Agricultural Research Institute**

| Name | From (date) | Till (date) |
|---|---|---|
| Ms. Surabhi Jain (RA) | 09-05-2005 | 31-03-2007 |
| Shri. Ram Niwas Yadav (SRF) | 03-05-2005 | 31-03-2007 |
| Shri. Raj Kumar Singh (SRF) | 25-04-2005 | 31-10-2006 |
| Shri. Sudhaker Rao (SRF) | 13-12-2005 | 12-12-2006 |
| Shri. Shailendra Tripathi (SRF) | 20-04-2005 | 31-03-2007 |
| Shri. Ajay Kumar Tomar (SRF) | 21-04-2005 | 31-03-2007 |

**Central Plantation Crop Research Institute, KASARAGOD**

| Name | From (date) | Till (date) |
|---|---|---|
| M.S. Rajeev (SRF) | 28.1.05 | 22.4.06 |
| A. Balakrishnan (SRF) | 31.1.05 | 18.6.05 |
| C. Sibin (SRF) | 10.2.05 | 31.7.05 |
| M.T. Vinayan (SRF) | 25.7.05 | 06.5.06 |
| Suresh (SRF)<br>Smt. Sapna (SRF)<br>***Two SRF positions at CPCRI, Kasaragod are currently vacant. The process for selection of SRFs is in progress.*** | 20.9.05<br>May, 2006 | 15.3.06<br>To date |

**Central Research Institute for Dryland Agriculture, HYDERABAD**

| Name | From (date) | Till (date) |
|---|---|---|
| N. Sreedharacharya (RA) | 01-01-2005 | Till date |
| P. Lakshmipati (SRF) | 01-01-2005 | 31-07-2005 |
| Ratna Kumar (SRF) | 01-01-2005 | Till date |
| Masood Khan (SRF) | 03-01-2005 | Till date |
| V. Raja Narendar (SRF) | 04-04-2005 | Till date |

**Jawahar Lal Nehru Krishi Vishwavidyalaya, JABALPUR**

| Name | From (date) | To |
|---|---|---|
| A. K. Patel (SRF) | 03-01-2005 | 23-01-2007 |
| D. K. Harinkhede (SRF) | 07-01-2005 | 06-02-2006 |
| S. B. Sharma (SRF) | 27-01-2005 | Contd. |
| Sanjay jain (SRF) | 28-01-2005 | Contd. |
| Mrs. Preeti Sagar Nayak (SRF) | 15-05-2006 | Contd. |
| Shri Chinmaya Kumar Das | 05-08-2006 | Contd. |

**Indian Institute of Horticultural Research, BANGALORE**

| **Name** | **From (date)** | **Till (date)** |
|---|---|---|
| Miss.V.H.Prabhavathy | 04-08-2006 | Contd. |
| Miss.Sunitha Neelmani Minz | 03-08-2006 | Contd. |
| Mr.Sridhara | 29-07-2006 | 28-02-2007 |
| Miss Ashwini | 15-12-2005 | Contd. |

**CSK Himachal Pradesh Agricultural University, PALAMPUR**

| Name | From (date) | Till (date) |
|---|---|---|
| Dr Sanjay Kumar (RA) | 15-02-2005 | Till date |
| Mr Anurag Saklani (SRF) | 24-03-2005 | Till date |
| Mr Shamsher Singh (SRF) | 15-02-2005 | Till date |

**University of Horticulture and Forestry, SOLAN**

| **Name** | **From (date)** | **Till (date)** |
|---|---|---|
| Mr. Krishan Chand (RA) | 02-02-2005 | Contd. |
| Dr. Naresh Kumar (SRF) | 02-02-2005 | Contd. |
| Mr. Narender Singh Thakur (SRF) | 02-02-2005 | 14-02-2006 |
| Mr. Sanjeev Kumar (SAF) | 27-03-2006 | Contd. |
| Miss Sandhya Goswami (SRF) | 27-10-2006 | Contd. |

**Indian Institute of Soil Science, Bhopal**

| **Name** | **From (date)** | **Till (date)** |
|---|---|---|
| Rahul Srivastava | 24-03-2005 | continuing |
| Anil Kumar Pal | 30-03-2005 | continuing |
| Mrs. Swati Yadav | 14-09-2005 | continuing |

**Central Soil and Water Conservation Research and Training Institute, DEHRADUN**

| Name | From (date) | To |
|---|---|---|
| Shri. Ashish Mudgal (SRF) | 15-02-2005 | 30-06-2006 |
| Smt. Kumari Lali (SRF) | 7-03-2005 | 14-03-2007 |
| Shri. Dhruba Jyoti Das (SRF) | 29-04-2005 | 14-11-2005 |
| Shri Md. Shahid Ali (SRF) | 12-05-2006 | Contd. |

**ICAR Research Complex for Eastern Region, PATNA**

| Name | From (date) | Till (date) |
|---|---|---|
| Mr. Sudarshan Prasad | 03-06-2005 | 19-02-2007 |
| Ms. Vandana Chhabra | 12-07-2005 | Contd. |
| Ms. Baby Tabassum | 30-06-2005 | 29-10-2005 |
| Ms. Anamika | 09-12-2005 | Contd. |

**National Dairy Research Institute, KARNAL**

| Name | From (Date) | Till (Date) |
|---|---|---|
| Mr. Ashok Kumar (RA) | 23-11-2005 | 31-12-2007 |
| Mr. Asvene K. Sharma (SRF) | 14-11-2005 | 21-01-2007 |
| Mr. Sandeep K. Gupta (SRF) | 4-2-2006 | Contd. |

**Central Marine Fisheries Research Institute, COCHIN**

| Name | From (date) | Till (date) |
|---|---|---|
| M. Hussain Ali | 30-12-2004 | 31-03-2007 |
| Thara K. J | 29-12-2004 | 31-05-2006 |
| Harish Nayak T | 28-12-2004 | 28-02-2007 |
| Jasper B | 05-01-2005 | 31-03-2007 |
| Rejomon George | 17-07-2006 | 31-03-2007 |

**Central Inland Fisheries Research Institute, BARRACKPORE**

| Name | From (date) | Till (date) |
|---|---|---|
| Sri Sampat Maji | 05-01-2005 | 17-10-2006 |
| Sri Pankaj Kumar Srivastava | 05-01-2005 | Contd. |
| Sri Sumanto Dey | 10-01-2005 | Contd. |

**Water Technology Center, Tamil Nadu Agricultural University**

| Name | From (date) | Till (date) |
|---|---|---|
| S.K Natarajan (SRF) | 01-01-2005 | Till date |
| V.Kavita (SRF) | 01-01-2005 | Till date |
| G.Ramkumar (SRF) | 04-02-2005 | 25-11-2005 |
| R.Muralidharan (SRF) | 31-12-2004 | 25-02-2006 |
| V.Sudhalaksmi (SRF) | 03-04-2006 | Till date |

**Narendra Dev University of Agriculture and Technology, FAIZABAD**

| Name | From (date) | Till (date) |
|---|---|---|
| Shri Arvind Kumar Srivastava (SRF) | 02-04-2005 | 31-03-2007 |
| Shri Amit Chaturvedi (SRF) | 05-07-2005 | 31-03-2007 |
| Shri Satya Prakash | 31-12-2005 | 30-09-2006 |

**ANNEXURE 3: Budget allocation and expenditure of different Institutes**

| S.No. | Centre | Budget | Expenditure |
|---|---|---|---|
| 1 | I.A.R.I., New Delhi | 9963000 | 9915623 |
| 2 | CRIDA, Hyderabad | 7615000 | 5138777 |
| 3 | CPCRI, Kasaragod | 5345000 | 4198290 |
| 4 | I.I.H.R., Bangalore | 6279000 | 5677242 |
| 5 | JNKVV, Jabalpur | 5569000 | 4916445 |
| 6 | IISS, Bhopal | 4845000 | 3521910 |
| 7 | ICAR Res.Complex for Eastern Region, Patna | 5715000 | 2350947 |
| 8 | CS&WCR&T.I., Dehra Dun | 5365000 | 1558862 |
| 9 | DR.YSPU of H&F, Solan | 4615000 | 4582033 |
| 10 | CMFRI, Kochi | 6799000 | 6046245 |
| 11 | CIFRI, Barrackpore | 6100000 | 2483653 |
| 12 | N.D.R.I., Karnal | 6195000 | 2720661 |
| 13 | HPKVV, Palampur | 3690000 | 3384333 |
| 14 | T.N.A.U., Coimbatore | 4269000 | 3905396 |
| 15 | NDUA&T, Faizabad | 3695000 | 1588972 |
| 16 | Coordinating Center, IARI | 5028000 | 2424655 |
| | **Total** | **91087000** | **64414044** |

**ANNEXURE 4: Specific objectives of the individual centers**

**Indian Agricultural Research Institute**

- To document current knowledge base on impact, adaptation & vulnerability.
- To assess the impact of increased CO2 & temperature on the productivity and quality of rice, wheat, mustard and chickpea.
- To quantify the impact of climatic variability & climate change on insect-pest dynamics.
- To quantify the sources and sinks of green house gases in Indian Agriculture.
- To quantify the change in demand & supply of food in different scenarios of climate change.
- To use the above information for developing crop models for impact assessment of climate variability and climate change.

**Central Plantation Crop Research Institute, KASARAGOD**

- To document the current knowledge base on impact, adaptation and vulnerability of plantation crops to climatic variability and climate change.
- To quantify the relationship between historical weather and the performance of coconut and black pepper in different agro-climatic zones (In collaboration with Central Research Institute for Dryland Agriculture, Hyderabad).
- To quantify the impact of climate change on productivity of coconut and pepper in different agro-climatic zones.
- To screen germplasm of coconut and black pepper for quantifying the impact of climate change in different regions (response of selected cultivars will be studied).
- To evaluate the impact of increased temperature on growth and quality parameters.
- To develop crop models of coconut and pepper for quantifying the impact of climate change in different regions.
- To identify hot spots more prone to climate change and variability for management from plantation sector point of view (In collaboration with Central Research Institute for Dryland Agriculture, Hyderabad.
- To quantify the carbon sequestration potential of coconut crop.
- To study the socioeconomic aspects of climate change on coconut and pepper farming community.

**Central Research Institute for Dryland Agriculture, HYDERABAD**

- To identify climate change scenarios in rainfed districts of India.
- To study the impact of elevated $CO_2$ on important rainfed crops.
- To understand the Agroforestry potential in $CO_2$ sequestration as a mitigation strategy.
- To study the impact of climate change on the Dryland crop pests due to elevated $CO_2$ and temperature.

**Jawahar Lal Nehru Krishi Vishwavidyalaya, JABALPUR**

- To document the current knowledge base on impact, adaptation and vulnerability of agro-biodiversity to climatic variability and climate change.
- To collect, compile and analyze the historical data of weather and agrobio- diversity including medicinal plants, wild crop relatives and land races in different agro-climatic zones to establish trends in climate change and variability.
- To study (in-situ) the species distribution, population density and diversity of medicinal plants and wild crop relatives at different elevation with climatic variabilities in the biosphere reserve.
- To evaluate the impact of increased temperature on growth, phenology and quality parameters of medicinal plants bio-diversity.
- To screen wild crop relatives and land races for their adaptation to temperature in order to identify the genetic material for crop improvement.
- To assess the vulnerability of tribal ecosystem and risk management strategies adopted by tribals under changed climate situations.

**Indian Institute of Horticultural Research –BANGALORE**

- To document the current knowledge base on impact, adaptation and vulnerability of horticultural crops to climatic variability and climatic change.
- To study the effect of moisture, elevated $CO_2$ concentration and high temperature stress at different growth stages on flowering, dry matter production, distribution and yield of grapes, tomato, onion and rose.
- Assessment of impact of climate change scenarios on major pests of horticultural crops (grapes, onion and rose).
- To utilize the above information for developing crop and pest models of grapes, tomato, onion and rose.

**Himachal Pradesh Agriculture University, PALAMPUR**

- To develop a status paper on the possible effects of climate change on mountain agriculture.
- To study the past trends in climatic parameters and their association with land use changes, crop yields and other agricultural activities, socio-economic status and livelihood options in different regions.
- To study the impact of climate change on land use (changing cropping pattern, new available areas for cultivation ï shifting apple belts etc.) in the mountains
- To prepare a glacier inventory, glacier mass balance and water availability scenario as affected by global warming in different regions.
- To suggest alternate land use and livelihood options for mountain farmers to cope up with the adverse impact of climate change.
- To document the current knowledge base on impact, adaptation and vulnerability of agroforestry to climatic variability and climatic change.
- To assess the current carbon storage capacity of different agroforestry land use systems in agricultural landscapes, pastures and non-forest areas.
- To determine the strategies to enhance the carbon storage capabilities of trees- crop-animal system through manipulation of woody component (trees & shrubs) and organic builds up in soils.

- To evolve suitable agroforestry models for different eco-regions compatible with socio-economic conditions as viable and efficient carbon sinks.
- To examine the cost benefit of carbon sequestration and opportunities for carbon trading.

**Dr. Y.S. Parmar, University of Horticulture and Forestry, Nauni- SOLAN**

- Impact of climate change on weather and apple productivity trend in Himachal Pradesh.
- Adaptability of apple crop to weather trends and adaptation strategies by the growers.
- Carbon sequestration potential of agroforestry systems in different climate types and management regimes.
- Evaluation and preparation of the carbon inventories of the different agroforest for trading carbon under CDM.

**Indian Institute of Soil Science, Bhopal**

- To document the current knowledge base of impact of climatic variability and climate change on soil organic carbon stocks in different agro-ecological regions.
- To evaluate the soil carbon stock under different agro-ecological regions of India.
- To find out the relationship between soil carbon stocks and the factors affecting it.
- To determine the possibility of carbon sequestration in soil.
- To assess the resource conservation technologies (RCTs) for enhancing carbon sequestration in soil.
- To improve the available models for soil organic matter dynamics by incorporating the relationships derived from this study.

**Central Soil and Water Conservation Research and Training Institute – DEHRADUN**

- To document the current knowledge base on impact of climatic variability on runoff, soil erosion and crop productivity following watershed approach.
- To develop and utilize simulation models to quantify the impact of climatic variability on runoff and soil erosion in different agro-climatic regions of India.
- To upscale the above information at country level using GIS and simulation models.
- To examine trade-offs among production, income and conservation of resources in representative watersheds in different agro-ecological regions to suggest strategies for utilizing watersheds as an adaptation strategy.

**ICAR Research Complex for Eastern Region, PATNA**

- To document the current knowledge base on impact, adaptation and vulnerability of water resources to climatic variability and climate change.
- To identify the areas having greater risk of increased duration and frequency of flooding and droughts in the selected sub basins.
- To simulate the impact of global environmental change on the hydrology and spatial and temporal availability of water in the selected sub basins.
- To establish linkage among hydrologic, irrigation and crop growth simulation models for assessing impact on production and socio economic aspects.

- To suggest the possible management water demand and adaptation strategies in meeting / alleviating perceived shortage of water under projected global environmental change scenarios.

**National Dairy Research Institute – KARNAL**

- To document the current knowledge based on Impact, Adaptation and Vulnerability of livestock to climate variability and climate change.
- To understand interaction between stress hormones, free radicals, immunity and animal productivity.
- To quantify the impact of climatic stress on cattle and buffaloes and the current adaptation strategies.
- To know relationship between animal productivity and methane emission with specific reference to Indian cattle and buffaloes.
- Mitigation and alleviation of stress by shelter management and modulation of immune system by cytokines, interferon and chromium supplementation.

**Central Marine Fisheries Research Institute – COCHIN**

- To study the direct and indirect impact of climate change on marine fisheries using historical data.
- To identify marine fish species vulnerable to climate change.
- To study the impact of climate changes on sensitive areas such as mangroves and coral reefs.
- To create data base on key environmental parameters indicators for tracking, future assessment and prediction of impact of climate change on marine fishes.
- Identification of adaptive measures based on the findings of the study.

**Central Inland Fisheries Research Institute –BARRACKPORE**

- To document the current knowledge base on impact, adaptation and vulnerability of inland fisheries to climatic variability and climatic change.
- To study the effects of temperature change in selected water bodies through laboratory-based experiments.
- To assess the long-term impact of climate change on fish production and their food in rivers.
- To study the impact of temperature change on fishes at the primary, secondary and tertiary levels of biological organization.
- To study the impact of climate change on the migration and geographic distribution of fishes.
- To monitor the incidence and occurring of diseases in fish in selected water bodies due to environmental change.
- To assess the socioeconomic impact of global warming.

**Water Technology Center, Tamil Nadu Agricultural University**

- To document the current status of risk assessment, especially due to climatic variables and their utilization in crop insurance.
- To quantify the vulnerability of selected coastal ecosystems to climatic variability and climate change especially sea level rise
- To develop recommendation strategies that can minimize the adverse effects of sea level rise on the livelihoods of affected population
- To characterize spatial and temporal magnitude of risk is selected agro- ecological regions and its relationship with input management and yield loss
- To conduct a case study to illustrate the utilization of risk characterization for calculating insurance premiums
- To explore the suitability crop insurance as an effective tool for income stabilization among other options, given the underlying yield and income linkages

**Narendra Dev University of Agriculture and Technology, FAIZABAD**

- To study the data base sensitivity as to access the weather/climatic trends in relation to agricultural Productivity in Eastern India.
- To quantify the varietals options/management and livestock production for adaptation of farmers in changing scenario of climate / climatic variability.
- To study the socio-economic status and work out the cost-benefit ratio of rural house hold in different Agro-climatic zones.
- To Study the adaptive & vulnerability for subsistence farming under varied climatic condition.

**ANNEXTURE 5: Executive Summary by Centre**

**Indian Agricultural Research Institute, New Delhi**

- Trend analysis of last 40 yrs climate data of North western region of India showed increase in both maximum and minimum temperatures.
- Mean seasonal temperature of > $33^0$C and < $27^0$C reduced rice yield in the field experiments. Early reproductive stage was most sensitive to high temperature and yield declined due to reduction in panicles /m2, grains/panicle and spiklet fertility. Plants exposed to continuous heat were relatively more adapted with less reduction in yield.
- High temperature >$35^0$C around flowering increased pollen sterility in rice and temperature >$32^0$C reduced pollen germination on stigma. Aromatic rice was more sensitive than non-aromatic rice.
- High temperature reduced test weight, grain elongation and aroma in basmati rice. It increased amylose content (@ 0.44% per $^0$C) and gelatinization temperature.
- In wheat, a narrow range of mean season temperature of 17-$22^0$C was optimum for grain yield in bread and durum wheat. Test weight and hectoliter weight declined sharply and protein% increased with increase in temperature during grain growth period. The impact was less in durum compared to bread wheat. Beta-carotene of durum wheat was more stable.
- Simulation studies indicate a possibility of loss of 4-5 million tons in wheat production with every rise of $1^o$C temperature throughout the growing period even after considering carbon fertilization (but no adaptation benefits). It assumes that irrigation would remain available in future at todayǿs levels.
- It is, however, possible for farmers and other stakeholders to adapt to a limited extent and reduce the losses. Simple adaptations such as change in planting dates and crop varieties could help in reducing impacts of climate change to some extent. For example, the Indian Agricultural Research Institute study quoted above indicates that losses in wheat production can be reduced from 4-5 million tons to 1-2 million tons if a large percentage of farmers could change to timely planting.
- Adapted wheat genotypes to varying climatic conditions were identified and morpho-physiological traits associated with yield stability were standardized.
- On the basis of a functional model developed on fecundity and climate change scenario of 2050, it was concluded that in general most places in India might show some decrease in fecundity of Chillo.
- Soil organic carbon stocks in IGP region was predicted by Introductory Carbon Balance (ICBM) model. Impact of temperature on microbial community structure pattern in different carbon scenarios was evaluated. The temperature sensitivity of soil organic matter decomposition was affected in the low carbon and high carbon scenario as the temperature dependence of resistant carbon is significantly different from the labile carbon pool.
- Spatial distribution of GHGs calculated from Infocrop model indicated higher GWP in intensely cultivated regions of Indo-Gangetic plains, coastal Andhra Pradesh & Orissa. No tillage in wheat mitigated GWP significantly but had no effect in rice cultivation.

**Central Plantation Crops Research Institute -Kasaragod**

- ***Recent trends in weather, climate, production and productivity of coconut and pepper:*** Warming trends in most of the coconut growing areas; Dry spells are in increasing trends in Karnataka and Kerala whereas reducing trends in coastal AP and coastal MS; Coconut productivity increased over past 50 years except recent declining trends in maidan Karnataka and Coimbatore dist (TN) due to consecutive droughts; General warming trends coincided with decreasing pepper productivity.

- ***Extreme events in weather/climate and effect on coconut yield: Droughts and cyclone:*** Consecutive droughts in Coimbatore dist (TN) reduced the coconut production by about 3 lakh nuts/year for 4 years; Productivity loss was to the tune of about 3500 nuts/ha/year; Loss due to 1996 cyclone in Konaseema (AP) was to the tune of 2200 lakh nuts/year in 6 years; Productivity was reduced by 6200 nuts/ha/year in E. Godavari dist and by ~4100 nuts/ha/year in AP.

- ***Yield deviation projections in different scenarios:*** Maidan parts of Karnataka, Eastern TN, coastal AP, Pondicherry, WB and Assam in decreasing order are found to be hot spots as per different HadCM3 model scenarios of climate change; Coconut yield deviation projections indicated negative trends in coastal MS, South-East TN, Coastal AP and WB in different scenarios (A2a, A2b, A2c, A1F, B2a, B2b of HadCM3 model) for 2020, 2050 and 2080; No change in productivity was projected in coastal Karnataka and Kerala. Pepper productivity also did not different significantly in different scenarios

- ***Growth response of coconut seedlings and pepper to elevated temperature and $CO_2$ levels:*** In OTC experiments among 3 cultivars and 2 hybrids, COD has shown early response to elevated $CO_2$ (500 and 700 ppm) and elevated temp. (2 $^oC$) after 3 months of exposure. Increase in shoot height, leaf area and shoot dry matter due to elevated $CO_2$ was to the tune of 36% and decrease in those in elevated temp. (2 $^oC$) was to the tune of 40% over chamber control; In pepper, the percentage variation was <10 for both leaf area and plant height after 4 months of growth at elevated temperatures (2 and 2.7 $^oC$)

- Regression analysis indicated increase in T min increased the leaf emergence rate; increase in T max increased inflorescence emergence rate; increase in RH increased the GDD requirement for inflorescence emergence; pistillate flower production has curvilinear relationship with rainfall/month (150mm/month-opt), T min (15 $^oC$-opt) and RH (70%-opt); nut retention has curvilinear relationship with T max (32 $^oC$-opt) and T min (20 $^oC$-opt); coconut yields increase up to 44 $^oC$ of Tmax and then decline; Sapflow studies indicated that 50 L sapflow is required for development of one nut and Sapflow is highly influenced by VPD and other weather variables

- ***Quality of coconut and pepper in relation to Climate change scenarios:*** Variation in MCFAs in oil from WCT grown at different agro-climatic zones was found maximum in nuts harvested during Jan, Oct and Jul and least in those harvested in April; In pepper, samples from higher elevation (Wynad and Idukki) showed lower oil and piperine content and they also have Sabinine+myrcine.

- ***Carbon sequestration and carbon stocks in coconut:*** Annual C sequestration in coconut above ground biomass varied from 15 CERs to 35 CERs depending on cultivar, agro-climatic zone, soil type and management; Annually sequestered carbon stocked in to stem in the range of 0. 3 to 2.3 CERs; Standing C stocks in 16 year old coconut cultivars in different agro-climatic zones varied from 15 CERS to 60 CERs; Annual C sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils

- ***Coconut simulation model:*** A coconut simulation model, developed by adopting InfoCrop generic model, was validated and $R^2$ for nut yield was 0.86 and for DM partitioning was 0.95. The model is being used for climate change impact assessments.
- ***Socio-economic analysis on impact of drought in Coconut growing area:*** More than 2 lakh palms were dead and about 6 lakh palms were severely/partially affected due to drought in Coimbatore (T.N) and Tumkur (Karnataka) districts; Farmers who adopted soil moisture conservation practices or drip irrigation could reduce the drought impact on their plantations; In drought affected coconut gardens, farmers adapted short duration pulses, oil seeds and millets for their sustenance; The demand supply gap will increase for coconut in future scenarios

**Central Research Institute for Dryland Agriculture-Hyderabad**

- Monthly rainfall data of 3000 stations have been collected. Data of 1504 Rainfed districts identified by NATP directorate for Rainfed has been identified for analysis. RDBMS developed and the data has been stored in MS-Access database and catalogue prepared.
- Analysis of long-term rainfall trends and cyclical variations has been carried out. Studies on annual rainfall variability, shifts in monthly rainfall pattern, extreme rainfall and temperature extremes, mean Annual Rainfall variability over different periods, frequencies of extreme maximum temperatures in summer and minimum temperatures in winter has been carried out.
- Two generations of castor crop showed significant response under elevated $CO_2$ levels (700 & 550 ppm) in terms of growth, biomass and yield. The growth characters *viz.*, root and shoot lengths, root shoot ratios, leaf area, root, stem, and leaf dry weights and specific leaf area were fund to be significant at 550 and 700ppm $CO_2$ in both the generations.
- The response of second-generation crop was similar to the last season trend and all the growth characters showed maximum response at 700 ppm $CO_2$.The difference in response was minimized among the treatments when the last season seed from different treatments grown under open field conditions.
- The seed yield of primaries and 100 seed weight was more under 700 ppm when compared with 550ppm.Both elevated $CO_2$ levels increased the oil content and the response was more prominent in second-generation crop.
- High $CO_2$ foliage was 8 % more digestible than ambient $CO_2$ foliage. Although efficiency of conversion digested food (ECD) appeared to decrease 40% markedly in larvae fed high $CO_2$ .ECD values decreased moderately for larvae fed elevated $CO_2$. Larvae were much less efficient in converting digested castor in to body mass. The impact of elevated $CO_2$ on relative growth rates of insect was strongly influenced by both host mediated factor (elevated $CO_2$) and direct effect of $CO_2$ and temperature decreasing in larvae fed castor.
- The larval duration was more in case of groundnut (22-24 days) followed by blackgram (21 days) and castor (19 days) crops under elevated $CO_2$ (700-550 ppm).

  Results indicated that the predicted pest incidence would be low during (2020) and moderate during 2050 and 2080 years of Hyderabad area. The polyphenol concentration was more in castor under elevated $CO_2$ than the rest of the treatments. But in case of groundnut variation of polyphenols was not much noticed among the treatments.

**Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur**

- The climate change is likely to have major impact in the predominant rainfed agriculture of the state of Madhya Pradesh. Due to stress prone crop growing conditions, abiotic stresses already take away a major chunk of potential productivity of the crops. In future, such stresses may become much more intense and frequent in occurrence, consequently, all aspects of agricultural production- including biodiversity will be affected.
- Rainfall and temperature trend analysis in relation to productivity changes in Chickpea and Wheat at four environments namely Jabalpur, Chhindwara, Gwalior and Hoshangabad showed that rainfall exhibited positive influence in same regions with low rainfall and adverse in others while, increased temperature has negative influence on productivity over the years.
- Altitudinal, temporal and spatial variation in maximum and minimum temperature and rainfall at Pachmarhi Biosphere Reserve has significantly influenced the quality of medicinal plants.
- The quality of economically viable medicinal plants Isabgol and Chandrasur grown in larger part of Madhya Pradesh have shown positive association between high thermal stress with proximate principles. Besides Ashwagandha, Safed musli and Chandrasur have shown increased secondary metabolites accumulation namely Withanolide, Saponine and Simapic acid respectively.

**Indian Institute Of Horticultural Research, Bangalore**

- The trend analysis of the productivity changes over the years in relation to changes in climatic factors, viz., minimum and maximum temperatures and rainfall, for different seasons was carried out in tomato and onion for major growing areas of Karnataka and Maharashtra. The trend analysis for Nashik region showed that, during Kharif season, increase in both maximum and minimum temperatures over the years influenced the productivity of onion but rainfall had a negative influence. In Rabi maximum and minimum temperatures had negative influence, but rainfall had a low positive influence. The trend analysis of tomato productivity for Bangalore region showed that during Kharif season minimum and maximum temperatures and rainfall had positive influence over the years.
- The impact assessment of different climate change scenarios on a particular crop for various growing regions could be made by using crop simulation model. Hence, INFOCROP simulation model, a generic model, developed by Aggarwal *et al*., 2004 was adopted for tomato and onion. To adopt this model, historic data was collected, analyzed and growth and development was conceptualized. The model was calibrated from the data obtained from field experiments for determinate and indeterminate cultivars in tomato and four important cultivars of onion, grown under potential conditions.
- In order to assess the phenology of grapes in different grape growing areas of Maharashtra and Karnataka, the summation of growing degree-days available during the vine growth period was worked out. The average monthly maximum and minimum temperatures, after the fore-pruning was also compared for these grape growing areas. In Nashik and Bangalore, where lower degree days are available, more time is taken for fruit maturation. The information on time of fore pruning and days taken for different phonological stages, bud burst, flowering, veraison and maturity was collected from Nashik, Pune, Sangli, Solapur, Bijapur and Bangalore. A wide period of pruning is followed in these areas. This information could be used in assessing the impact of climate

change on phenology and quality of grapes in these regions under different climate change scenarios.

- Pest prediction equations were developed for grape thrips in relation to maximum temperature; the incidence was significantly and positively correlated with maximum temperature. In Nashik region onion thrips incidence during August month was highly correlated with increase in temperature over the years. Trend analysis showed that in Nashik region minimum temperature was found to be positively influencing the thrips incidence in onion. It was observed that thrips on rose required 265 and aphids 119 thermal day degrees (TDD) for development under field conditions in Bangalore. Thermal day degrees required for the development of thrips and aphids on rose for different climate change scenarios was worked out for Bangalore conditions.

**CSK Himachal Pradesh Agricultural University Palampur**

- **A climatic elements trend in H.P.-There is** significant decrease of water surplus during October to March and slight increase in *kharif* months. The rainfall decreased at the rate of 14.9 mm per year (-267.9), maximum and minimum temperature increased by 0.1 & 0.4ºC per year. During rabi season minimum temperature decreased by 0.1ºC but maximum temperature showed an increase by 0.6ºC. Evaporation registered decrease at the rate of 2.2mm (37.2mm) in areas below 700masl.The areas above 700 to 1200m asl was found to be highly vulnerable for water surplus. Water deficit increased by more than 50 percent compared to 1974 to 1984. The mean temperature change showed increasing trend in general throughout the year except June (less than -0.50$^0$C). Water surplus decreased very sharply more than 150%. There was more than 150% deficit in *kharif* season in areas lying between 1200 to 2200 masl. The areas above 2000 masl in Theog valley showed an increase of 10 % in soil water availability. Rainfall decrease was less compare to lower elevation region (26.5mm) and 1.89mm.
- **Shift of apple belt in recent years-**The shift of apple belt upwards due to decreasing chilling hourô s requirements of the crop has been observed in apple growing areas of Himachal Pradesh. The new areas of apple cultivation have appeared in Lahaul and Spitti and upper reaches of Kinnaur district of Himachal Pradesh, as evident from the farmersô survey carried out in the regions and the analysis of secondary data. There is increasing temperature trends during November to March months. Past 18 years data base showed that mean temperature is decreasing at the rate of 0.09$^0$C to 2.1$^0$C per year from November to April whereas maximum temperature showed an increasing trend of 5.8$^0$C to 8.1$^0$C during November to April. In another apple growing region the data exhibited the same situation in the decrease of chill units. In recent years, the total area under apple in the entire state have fallen from 92,820 ha in 2001-02 to 86,202 ha in 2004-05 whereas, area in Lahaul & Spitti and Kinnaur district which lie above 2500 masl showed increase every year in last ten years.
- **Impact of climate change on crop performance-**The reproductive phase (days to flowering) and maturity phase was reduced by five and fifteen days in early sown and late sown wheat crop at Palm valley of Himachal Pradesh. The maturity phase was observed to be extended by four days but reproductive phase shortened by nineteen days in last fifteen years in early sown crop. Similarly, linseed crop, which is sown during the period between October 10 to November 10 in the region, also indicated decrease in days to reproductive and maturity phase in all the varieties. The data on reproductive and maturity phase of the barley crop was observed at Bajaura in Kullu Valley. The reproductive and maturity phase enhanced by ten to twenty six days in the region.

The kharif season crops at Palampur behaved differently. The soybean crop, which was sown during 10th to 22nd June, showed increase in number of days to attain flowering and maturity phases at Palampur. The June months in last 30 years data indicated decrease of 0.8 $^{O}$C in last three decade which could have delayed the crop maturity and flowering in soybean.

- **Impact of climate change on productivity of wheat:** The wheat crop yield showed reduction in productivity in all scenarios for future rainfall of 2020, 2050 and 2080 at elevation of 700 to 1200 masl. In all other elevation above 1200m and below 700masl showed increase in crop productivity. Wheat productivity showed increase in places up to 1500 masl and then decrease or negative sensitivity with respect to maximum and minimum temperature for future in all scenarios.
- **Impact of climate change on productivity of rice**: The rice crop productivity would increase at Palampur. The productivity showed decrease at Dhaulakuan and Bajaura region. The magnitude of increase or decrease was highest in 2080 for future rainfall followed by 2050 and 2020. Rice productivity in 2020, 2050 and 2080 in all scenarios for maximum and minimum temperature showed decrease above 700 masl whereas in the areas below 700m, projections are for increase in yield.

**Dr. Y.S. Parmar, University of Horticulture and Forestry, Nauni- Solan (H.P.)**

- Analysis of the climate data of subtropical plain, subtropical low hills, wet temperate high hills and dry temperate high hills for the last 20-25 years of northwestern Himalayan regions reveals that the minimum temperature in the subtropical plains, subtropical low hill zone is declining, whereas, in the wet and dry temperate high hills both minimum and maximum temperature is showing increasing trends.
- Rainfall patterns in the subtropical plains have shown an increased trend. Whereas, in the subtropical hill, sub-humid mid hill zone, wet temperate high hills zone and dry temperate the rainfall has shown a declining trend during the last 20-25 years.
- Snowfall is also showing a declining trend in a significant manner in both wet temperate and dry temperate zone.
- Agroforestry has the maximum carbon sequestration potential in subtropical climate and the least in dry temperate. Its carbon sequestration potential decreased with the increase in altitudinal gradient from 468 m asl ï 2100 m asl.
- Agri-silviculture (*Toona ciliata* + Maize - Wheat) and agri- horti-silviculture (*Mangifera indica* + *Toona ciliate* + Maize - Wheat) are the most suitable agroforestry systems to be used in for carbon sequestration in subtropical climate type.
- Agri-horticulture has been the most suitable system for carbon sequestration in temperate climate among the four climate types. Apple+ Pea followed by Apple + Cabbage-Frenchbean formed the best combinations.
- Silvi- pasture system with its functional units Pinus *roxburghii* + natural grass in sub temperate climate, and Salix + natural grass in dry temperate was the promising agroforestry system for sequestering carbon.
- Trend predicted apple productivity in Kullu, Shimla as well as overall average productivity of the state has shown declining trend. Average state productivity in 1980 - 81 was 7.06 tonnes ha$^{-1}$ that decreased to 4.65 tonnes ha$^{-1}$ in 2004-05. Dry temperate region of Kinnaur have shown increased trend predicted productivity of apple contrary to wet temperate zone and overall average of the HP state. Apple productivity in wet temperate region of Kullu and Shimla has shown a deviation of 0.245 tones ha$^{-1}$ for every unit deviation in chilling units. Overall the chilling unit accumulation has shown a

declining trend in the entire apple zone. However, in dry temperate zone of Kinnaur a very little deviation of 0.0102 tones $ha^{-1}$ per chill unit was recorded.

- The peoples at lower most altitude particularly, in Kullu district have shifted from apple to vegetable crops like cauliflower, cabbage, peas, carrot, and other fruit crops-pomegranate, kiwi and pear cultivation. And this shift is proving to be quite beneficial to the growers. Whereas, in Shimla district, where the valleys are located at comparatively higher location than Kullu district the orchardists have shifted from high chilling requiring cultivars (Royal Delicious) to low chilling requiring cultivars of Vance delicious, Red Chief and Oregon spur, etc. The shift is also proving to be highly beneficial as the fruits from low chilling cultivars reaches the market earlier and hence fetches a very high price. At middle altitude of Kullu district the people are shifting from high chilling requiring cultivars of apple to low chilling requiring cultivars of Tydeman's early, Coop-12, Snowmit, etc. and other fruits and vegetable crops like kiwi, pomegranate, peas, cauliflower, garlic, etc. At the middle altitude of Shimla district the people are shifting from agricultural crop to apple and potato cultivation totally. At the highest altitude of the two districts, people are benefited the most because of increased temperature and consequently lengthened growing period. Here, the people are giving the cultivation of traditional agricultural crops and are now growing apple, potato and vegetable of highest quality, which fetches them remunerative prices in both domestic as well cosmopolitan market of the country.
- Regional climatic zonewise carbon inventory of agroforestry systems of Himachal Pradesh based on revised 1996 IPCC Guidelines for National Greenhouse Gas Inventory has been prepared. The agroforestry systems inventories were agri-silviculture, agri-horti-silviculture, agri-horticulture and silvi-pasture systems under the business as usual scenario i.e. current management scenario agri-silviculture and silvi-pasture systems were evaluated to contribute positively towards carbon sequestration whereas agri-horticulture and agri-horti-silviculture systems were found to release more carbon to the atmosphere.

**Indian Institute of Soil Science-Bhopal**

- A functional linear relationship between SOC stock and soil clay content, rainfall, maximum temperature and minimum temperature was developed using multilinear regression analysis. This functional linear relationship was utilized to estimate the soil SOC stocks in 2020,2050 and 2080.
- The maximum and minimum temperatures of the India grid locations are predicted to increase in 2020,2050 and 2080.Similarly the minimum increase in SOC is predicted to be 0.09,0.29 and 0.65Mg $ha^{-1}$ respectively in 2020,2050 and 2080in eastern Madhya Pradesh and parts of Chhattisgarh.
- The maximum decrease in SOC stock is predicted for southern Kerala and southern Tamil Nadu. In these regions the rainfall, maximum temperature and minimum temperature are expected to rise. however, the organic carbon content is expected to decrease.
- In general, percent macro aggregates was higher than micro all treatments and macro aggregates increased with depth. Tillage treatments had marked effect on aggregation upto a depth of 15 cm. Macro aggregates percent increased by 5% under no tillage at 0-5 cm and about 2% at 5-15 cm depth. A similar trend in total organic carbon of soil was seen.

**Central Soil & Water Conservation Research and Training Institute, Dehradun**

- It is projected that Peninsular India is going to be most vulnerable region for agriculture as soil and water conservation aspect shall be needed most extensively due to very high runoff and soil loss. Central India closely follows this trend. The North East Hill Region is very vulnerable as heavy silt loss from this region is going to affect the plain areas where the rivers originating from this region flows as soil loss to the tune of 25 t/ha is going to get deposited in the river and thus flooding the area. The Northern Himalayas are going to be least affected from the runoff and soil loss point of view. A decreasing trend of runoff and soil loss is ordered when we move from tropics to temperate region.

- The runoff at Pogalur, Coimbatore, and Tamilnadu is expected to increase by 6 to 12 times during 2071-2100 than that of 1961-1990. The runoff at Jonainala, Keonghargarh, and Orissa is projected to increase between 83 to 111 percent and at Belura, Akola, and Maharashtra between 142 to 182 per cent in comparison to the runoff of 1961-1990. The runoff at Antisar, Kheda, Gujarat is assessed to increase between 117 -227 percent during 2071-2100 than that of 1961-1990. The runoff at Almas,Tehri, Uttrakhand; Umiam, Shillong, Meghalaya and Udhagamandalam, Nilgiris, Tamilnadu is expected to increase by 56 to 132, 96 to 171 and 94 to 309 percent than the runoff available during 1961-90. Most of the increase in runoff has been observed during monsoon season.

- The AVSWAT model has been used to assess soil loss from various watersheds. The model has been calibrated and validated for annual soil loss observed from Almas watershed with $R^2$ value of 0.97. It is observed that Pogalur watershed is going to experience maximum soil loss (757 percent more) followed by Belura watershed (269 percent more), Umiam watershed (71 percent more), Antisar watershed (60 per cent more), Almas watershed (41 percent more), Jonainala watershed (29 per cent more) and least from Udhagamandalam watershed (4 per cent more) during 2071-2100 than that of 1961-1990. The Umiam watershed may yield soil loss of about 24.8 t $ha^{-1}$ $yr^{-1}$ during 2071-2010 than the soil loss of 14.5 t $ha^{-1}$ $yr^{-1}$ observed during 1961-1990. The Poglur watershed is having insignificant soil loss of 7 kg $ha^{-1}$ $yr^{-1}$ during 1961-1990. However, the soil loss in this area is going to increase to 60 kg $ha^{-1}$ $yr^{-1}$ and this loss is going to be detrimental from crop production point of view as this zone is having shallow soil depth and low productivity.

**ICAR Research Complex for Eastern Region, Patna**

- Trend analysis showed upward trend in mean monthly temperature and downward trend in mean monthly relative humidity (RH) in most of the stations in the Brahmani basin. In general there is decreasing trend (though non-significant) in mean monthly rainfall throughout the basin. Half of the stations (5 out of 10) showed increasing trend in annual and monsoon rain. But the significant increase in annual and monsoon rain was recorded only at Gomlai, whereas significant decrease in annual and post-monsoon rain was recorded at Dhenkanal. During post monsoon period (October-November), most of the stations (80%) showed increasing trend in rainfall. Trend analysis of streamflow using different statistical tests showed significant increase in mean monthly streamflow during Oct, Nov and Dec months, and also significant increase in the annual minimum and low flow (seven days minimum) series in all the four stations. Overall there is a significant increase in monthly streamflow in the month of October, November, December, March and April with maximum increase in the month of November followed by October, December, March and April.
- The capability of hydrological model MMS/PRMS to simulate reliable estimates of streamflow was demonstrated using distributed hydrological modeling by dividing the basin into nineteen different classes of Hydrological Response Units (HRUs) with a total 66 HRUs distributed over the basin. The calibration and validation of the model showed a good agreement between daily as well as monthly observed and simulated streamflow with coefficient of determination and modeling efficiency varying from 0.84 to 0.99 and 0.80 to 0.98, respectively.
- Simulation results indicated increase in mean annual streamflow at Jaraikela (25 and 31%), Tilga (58 and 38%), and Jenapur (25 and 31%) but decrease at Gomlai (-8 and -3.6%) in 2020 and 2050 under PRECIS RCM scenarios. Though there is increase in annual streamflow, a decrease in monthly streamflow, particularly during summer months (February ï June) in all the four gauging stations with maximum decrease at Gomlai was projected. Sensitivity analysis with hypothetical climate change scenarios indicated that streamflow in the basin is more sensitive to change in rainfall than change in precipitation.
- Modeling impact of climate change on actual evapotranspiration (AET) using SWAP model showed that percentage variation in AET ranged from 3.77 to 13.85 during kharif and 3.11 to 9.6% during rabi 2000 in Derjang Canal Command of Angul district in Orissa. These results indicate ramification of change in hydrological regime and water availability for irrigation and agriculture in the Brahmani basin.

**National Dairy Research Institute, Karnal**

- Impact of climate change and the potential direct effects of global warming on milk production of indigenous, crossbred cattle and buffaloes were evaluated using widely known GCM- UKMO- to represent possible scenarios of future climate ((SAS region-23, Ruosteenoja *et al.,* 2003). A temperature rise of 1.0° C with minor change in precipitation during March ï August for India (Region 23- HADCM3 A2/B2 scenario) will marginally decline milk production. A small change in Temperature-humidity index (THI) due to rise in temperature is not likely to cause much effect on physiological functions as animals have enough capacity to adapt, but both milk production and reproductive functions of cattle and buffaloes will be adversely affected by projected temperature rise of 2-6° C over existing temperatures for time slice 2070-2099.

- The negative impact of temperature rise due to global warming on total milk production for India has been estimated about 1.6 million tones in 2020 and more than 15 million tones in 2050. The partitioning of negative impact indicated that high producing crossbred cows and buffaloes will be affected more, accounting 0.4 million and 0.89 million respective annual decline in 2020. Negative impact on the productivity of indigenous cows will be about 0.33 million tones milk in 2020. The Northern India is likely to experience negative impact of global warming on milk production of both cattle and buffaloes during 2040-2069 and 2070-2099. The decline in milk production will be higher in crossbreds (0.63%) followed by buffalo (0.5%) and indigenous cattle (0.4%).

- An attempt was also made to map the THI load at district level and provide first estimate of economic losses from heat stress in dairy animals at the national and sub-national level. The weekly average THI was computed for 103 stations from normal maximum and minimum temperature and relative humidity. The weekly average THI was computed and weekly THI load was worked out at two different levels of threshold THI, that is, 72 and 78. The estimated annual loss at the all-India level is 1.8 million tones, that is, nearly 2 percent of the total milk production in the country. In value terms this amounts to a whopping Rs.2661.62 crores (at current prices). The economic losses were highest in UP (>Rs.350 crores) followed by Tamil Nadu, Rajasthan and W.Bengal .

- An inventory of enteric methane emission for 2006 has been prepared and an attempt has been made to reduce uncertainty in enteric methane emission of Indian livestock by following IPCC guidelines on good practice guidance and uncertainty reduction. Enteric Methane Emission of Indigenous, Crossbred cattle and Buffaloes has been estimated using Tier 2 methodology of IPCC. Tier 1 methodology and default factors of IPCC have been used for estimating enteric methane emissions for Sheep, Goats, equines, Pigs and other animals. In order to reduce uncertainty, the country specific methane emission factors were developed based on average methane emissions in expired air (0.01 to 0.08%) and eructation level (0.1 to 0.25%).

- The methane emission in expired air of growing, adult cattle and buffaloes maintained on different feeding regimes at the Institute were precisely monitored by the Open circuit method over different time intervals before and after feeding. The developed coefficients for Zebu, crossbreds and buffaloes were used for calculating enteric methane emissions. The body weights of livestock were categorized according to breed(s) and population in a state. The livestock population was also categorized for stall fed, grazing at small or large area, work and activity. The milk production and composition of milk of different breeds of cattle have also been accounted. The information on feed intake, digestibility, metabolizable energy, feedstuffs type and emission coefficients was also taken in to consideration for calculating emissions from different age groups of animals. The enteric emissions of livestock for the year 2006 were estimated based on the changes in livestock population structure from 1997 to 2003 (Livestock Census, 2003). The emissions for the year 2006 were estimated at 9.39 Tg/annum from both enteric emissions and manure management.

- In 2006, the contribution of indigenous cattle to enteric emission was 38% as against 41% in 2003 due to decline in unproductive indigenous cattle and working oxen population in 2006. The contribution of buffaloes to enteric methane emission was 43% in 2006, higher than other livestock due to rise in buffalo population.

- The growth gradients of animals were calculated for both accelerating phase and post point of inflection phase and relationship with Tmax, Tmin and THI were analyzed. The time to reach puberty and time lapse due to decline in growth rate were computed. Impact of temperature and humidity on growth was analyzed. The results indicated that both Zebu and crossbreds are affected due to rise in temperature. Time to attain puberty was observed to prolong from 5 to 17 days due to decline in growth rate at high temperatures. Crossbreds and buffaloes are affected more than Indigenous livestock. A rise of 2-6 °C due to global warming (time slices 2040-2069 and 2070-2099) will negatively impact growth, puberty and maturity of crossbreds and buffaloes and time to attain puberty of crossbreds and buffaloes will increase by one to two weeks due to their higher sensitivity to temperature than indigenous cattle.

- HSP70 and IL2 were assayed in the plasma of the exposed (45°C) buffalo heifers at the pre exposure, 2 h and 4 h exposure at 45°C in climatic chamber. The mean HSP70 content in the plasma of buffalo heifers was found to be $1.42 \pm 0.10$, $2.25 \pm 0.54$ and $1.76 \pm 0.30$ ng/100 at pre exposure, 2 h and 4 h exposure, respectively. The difference was statistically significant between the groups ($P<0.001$) and also within the periods. Between the periods effect was significant ($P<0.001$) but a non- significant difference was observed between pre exposure and 4 h exposure.
- The interrelationship between HSP70 and rectal temperature of the exposed buffalo heifers indicated that prior to exposure, buffalo heifers had a low HSP70 ($Y= -0.2201X + 9.884$, $R^2=0.4192$) but after 2 h exposure at $45^0$C a rise in HSP70 level was observed in plasma due to rise in rectal temperature. The interrelationship between HSP70 and heat storage was found to be negative at both 2 h and 4 h exposure at $45^0$C.
- The HSP70 concentration increased in plasma after 2 h exposure and the IL2 level in plasma decreased and Lymphocyte proliferation decreased. The concentration of IL2 and Lymphocyte proliferation was highest during the pre exposure period, but HSP70 concentration was lowest prior to the exposure of heifers.

**Central Marine Fisheries Research Institute, Cochin**

- **Distribution shift in the oil sardine**
  A rise in temperature as small as 1°C could have important and rapid effects on the mortality of some organisms and their geographical distributions. The oil sardine *Sardinella longiceps* is a tropical fish preferring temperature range of 27-29°C. During 1961-1976, the catch of oil sardine was predominantly (nearly 90% of all India catch) from 8°-12°N and 75°-77°E (southwest coast) where the SST ranged between 27.7°C and 28.0°C. The catch was very low (0.1-1.0%) from latitudes north of 15°N along the west coast (Maharashtra and Gujarat) where the SST range was between 25°C and 28°C in those years. There was no catch along the entire east coast. During 1997-2005, the oil sardine was recorded almost along the entire Indian coast (except off Gujarat and West Bengal coasts). The percentage of catch from latitudes north of 15°N along the west as well as east coasts increased; and catch from latitude north of 15°N (off West Bengal) was 0.1-1.0%. Considering the catch as surrogate of distribution it is found that the oil sardine has extended its northern and eastern boundaries of distribution. Oil sardine fishery did not exist before 1976 in the northern latitudes and along the east coast as the resource was not available. With warming of sea surface, the oil sardine is able to find temperature to its preference especially in the northern latitudes and eastern longitudes, thereby extending the distributional boundaries and establishing fisheries in larger coastal areas.

- **Shift in spawning season in threadfin breams**

  Whereas the oil sardine has responded to warming by way of extending the distributional boundaries, the dominant demersal fish, the threadfin breams have responded by shifting the spawning season off Chennai. Whereas 35.3% of the spawners of *Nemipterus japonicus* occurred during the warm months (April-September) in 1980, the number of spawners gradually reduced and only 5.0% of the spawners occurred during the same season in 2004. In 1980, it was observed that 64.7% of the spawners occurred during October-March, whereas as high as 95.0% of the spawners occurred during the same season in 2004. In other words, the spawning activity reduced in summer months and shifted towards cooler months. A similar trend was observed in *Nemipterus mesoprion* too. The data derived from ICOADS indicated that the average SST off Chennai increased from 28.5°C in the early 1980s to 29.0°C by 2005 during April - September, and from 27.6 to 28.1°C during October-March. Considering this, it may be concluded that the threadfin breams are adapted to shift the spawning activity to seasons when the temperature is around the preferred optima.

- **Vulnerability of corals to warming**

  Corals are a critical global resource, both biologically and in socioeconomic terms. From the present analysis, we considered the last two events of bleaching in 1998 and 2002 in the Gulf of Mannar (southeast coast of India). Sea surface temperature in the Indian seas warmed in these years, and considering the temperatures that prevailed at that time, and the projected increase in sea surface temperature (from SRES A2 scenario on monthly SST data for the years 2000-2099) in the forthcoming years, the number of future bleaching events in the Gulf of Mannar was projected. To understand the effect of elevated temperatures, the large scale (50 km) SST coral bleaching hot spot anomaly image provided by the United States National Oceanic and Atmospheric Administration, National Environmental Satellite data and Information Service (NOAA/ NESDIS) was used as a forecasting tool for potential bleaching conditions. The analysis suggests that the number of decadal bleaching events will remain between 0 and 3 during 2000-2099, but the catastrophic bleaching events of high intensity will increase from 0 during 2000-2009 to 10 during 2000-2099.

  On a simple inspection of this SRES A2 scenario, corals will be soon exposed to regular summer temperatures that will exceed the thermal thresholds observed over the last 20 years. For example, if the summer temperatures exceed 31.5°C for even a few weeks, then bleaching will eventuate in the Gulf of Mannar. If, as suggested by this scenario, these temperatures will be reached almost every summer from 2025 onwards; and then annual bleaching will become almost a certainty from 2050. Given the implication that reefs will not be able to sustain catastrophic events more than 3 times a decade, reef building corals are likely to disappear as dominant organisms on coral reefs between 2030 and 2040 and the reefs are likely to become remnant between 2050 and 2060 in the Gulf of Mannar. These initial analyses indicate that mobile organisms such as fish may adapt, at least temporarily but the stationary ones such as corals are immediately vulnerable.

**Central Inland Fisheries Research Institute, Barrackpore**

- Monsoon months are the breeding season of majority of fishes of the Ganga river system. Successful breeding is directly or indirectly related with the precipitation, alteration in flow pattern, current velocity and physico chemical changes especially temperature and turbidity. The catchments area of river Ganga is more in the plain. With decrease in the runoff, the required flow and turbidity of water essential for breeding of Indian major carps in the middle and lower stretch of river Ganga has been lost.
- Fish spawn quantity index revealed a diminishing trend. The declining in spawn availability from 2984 ml in the 1960s to 27 ml in recent years during 1994 to 2004 in the Ganga river system indicating the possible destruction of breeding ground of this river system. It also showed a continuing deterioration with decreasing percentage of major carps seed (78.62% in 1961-1965 to 34.48% in 2000-04).
- The total plankton was 2968 u/l in 1966, which decreased to about 979 u/l by 1981, 685 u/l by 1996 and 410 u/l by 2004.
- It is apparent that recent climatic patterns have brought about hydrological changes in the flow pattern of river Ganga. This has been one major factor resulting in erratic breeding and decline in fish spawn availability. As a result the total average fish landing in the Ganga river system declined from 85.21 tones during 1959 to 62.48 tones during 2004.
- The total number of genera of phytoplankton in the upper Ganga has declined in the last decades with the number coming down from 44 nos during 1987-89 to 42 nos during 1993-95. Contributions of some genera like Amphicampus, Tetracycles, Diatoma and Ceratoneus have become insignificant in riverine plankton. In the middle and lower Ganga sixty genera of phytoplankton was recorded during 1959 and declined to 44 numbers by 1996. In case of Zooplankton during the same period the number diminished from 38 to 26.
- A number of fish species, which were predominantly only available in the lower and middle Ganga in 1950s, are now recorded from the upper cold-water stretch upto Tehri. There is a distinct shift in biogeographical distribution of the Gangetic fishes.
- It is apparent that climatic changes have brought about hydrological changes in the flow pattern of river Ganga. This has been one major factor resulting in erratic breeding and decline in fish spawn availability. As a result the total average fish landing in the Ganga river system declined from 85.21 tones during 1959 to 62.48 tones during 2004.
- In recent years the phenomenon of Indian Major Carps maturing and spawning as early as March is observed in West Bengal with its breeding season extending from 110-120 days (Pre1980-85) to 160-170 days (2000-2005). As a result it has been possible to breed them twice in a year at an interval ranging from 30-60 days. A prime factor influencing this trend is elevated temperature, which stimulate the endocrine glands and help in the maturation of the gonads of Indian major carp. The average minimum and maximum temperature throughout the state has increased in the range of 0.1 to 0.9ºC**.** In the district 24 Parganas (N) both mean maximum and mean minimum air temperature have increased by 0.6764ºC & 0.3724ºC respectively and mean maximum and mean minimum water temperature have increased has increased by 1.668ºC, 0.135ºC respectively during the breeding months March to September.
- Analysis of the fish spawn quantity index in Ganga river system from available literature revealed decline in spawn availability from 2984 ml in the 1960s to 27 ml in recent years during 1994 to 2004. The failure of recruitment of young ones to the system is because of failure in breeding of the Indian Major Carps (IMC). Majority of fishes of the Ganga river system breed during the monsoon months. Decrease in precipitation over the years in the catchment areas of river Ganga, which is more in the plains along with increase in

temperature, the required flow and turbidity of the water essential for breeding of IMC is lost. This is reflected in the data of the breeding months analysed for Allahabad where there is a decrease in rainfall(2.5%) and an increase in water temperature(1.9 º C)Thus alteration in the climate in terms of rainfall and temperature has impacted the breeding and recruitment of Indian Major Carps in the river Ganga. Successful breeding is directly or indirectly related with the precipitation, alteration in flow pattern, current velocity and physico chemical changes especially temperature and turbidity.

- Impact of higher temperature on the reproductive integrity of mature *C.carpio* fish was investigated for 21 days. It revealed that increase in temperature above its normal spawning temperature of 30ºC resulted in lower Gonadosomatic index and estradiol levels in serum, impairing vitellogenesis in the fish.

**Tamil Nadu Agricultural University, Coimbatore**

- There are three approaches that have been widely used in the literature to measure the sensitivity of agricultural production to climate change, viz., cross-sectional models, agronomic-economic models, and agro-ecological zone models.
- Agronomic models estimated that chance in climate is expected to create both positive as well as negative impacts on rice yield of Tamil Nadu. Impact is more during Kharif season (Southwest monsoon) than in Rabi (Northeast monsoon) season. During Kharif season in 2020, 10 to 15 per cent reduction in rice yield is expected due to increase in temperature and change in rainfall. In 2050, 30 to 35 percent yield reduction and in 2080, up to 80 percent yield reduction is expected. Though, the reduction is found in all most all the districts, it is more pronounced in the major rice growing districts such as Thanjavur and Nagapattinam.
- Ricardian approach was used to analyse the impact of climate change using cross section and time series data for the state. Paddy is projected to decrease both in terms of area and productivity, resulting in lower production levels of about 13 percent in 2050 and 9 percent in 2020 from existing levels. Sugarcane is projected to decrease by 9.45 and 13.4 percent in terms of area and productivity in short term and about 13 and 9 percent in terms of area and productivity in the long term. Area under groundnut is projected to decrease by 5.12 and 3.65 percent in medium and long term. Groundnut yields are projected to decline by a 7.04 percent in medium term and by 5.36 percent in long term.
- Further, the results of the Multiple Goal Linear Programming (MGLP) model derived using the climate change variables had indicated that the maximum paddy production will be about 18, 14 and 4 thousand tonnes in 2020, 2050 and 2080 respectively as against the maximum production of 21 thousand tonnes at current levels.
- In sum all the approaches indicate the overall trend in yield and production of major crops in the State. The MGLP, however, will be helpful in deriving the optimum resource use pattern given the impact of the climate change.

**Narendra Dev University of Agriculture & Technology, Kumarganj, Faizabad.**

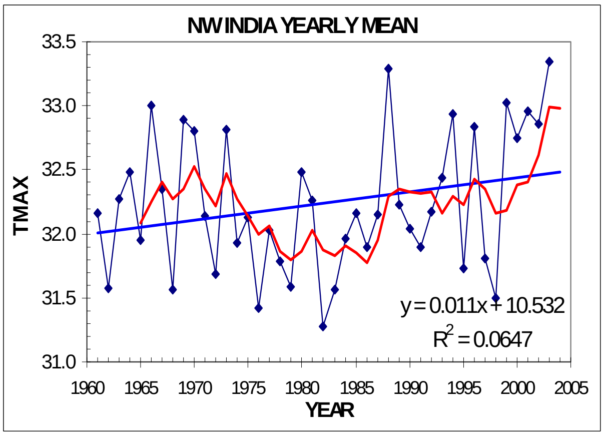
- The characteristics of rainfall of Eastern U.P. (i.e. onset and withdrawal of monsoon) from 1976 to 2004 indicates a shift of onset of monsoon from 4 to 6 days toward rainy season consequently length of rainy season also shifts on an average 5 to 6 days early.
- Wheat sowing is shifting towards December, which ultimately faces the high temperature at the time of grain filling.
- The milk yield of the cattle relatively unaffected with temperature range of 10-27$^{0}$C. The yield decreased after 27$^{0}$C with marked variation. It has also been estimated the milk production decreases approx. 1 kg for each degree Celsius rise in rectal temperature.

**ANNEXURE 6: Detailed Progress Report**

# Indian Agricultural Research Institute

***Analysis of recent climatic trends and variability***

In order to understand and quantify the recent climatic trends and climatic variability, homogenous monthly rainfall (1960-2003) and maximum and minimum temperatures (1960-2003) data for North West Region of India were analyzed. Using regression techniques, linear trends were fitted to the time series of weather variables at monthly, seasonal (Kharif & Rabi) and annual time scales. The Maximum temperature is showing increasing trends at Annual, Kharif and Rabi time scales, with a very sharp rise for years 2000 and beyond. The rate of increase during Kharif is significantly higher than during Rabi season. The Minimum temperature is also showing increasing trends at Annual, Kharif and Rabi time scales. Unlike Maximum temperature, its rate of increase during Rabi is much higher than during Kharif. The total annual rainfall is showing no trend in North West India.



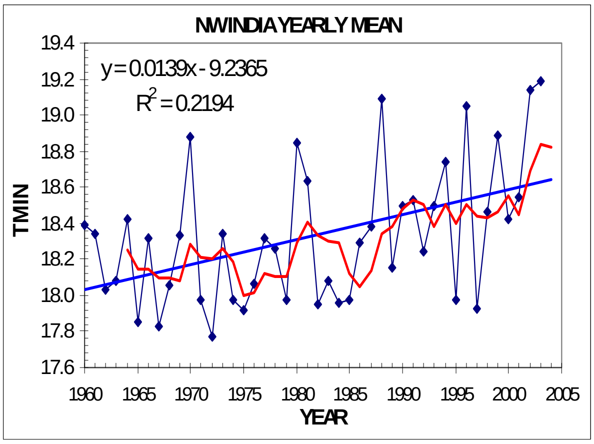




**Fig.1.** Trend in mean maximum and minimum temperatures in North Western region of India during 1960-2003.

***Impact Assessment of Future Climate Change on Crop Yields***

Work was carried out to develop and demonstrate a methodology for quantification of sensitivities of crop yields to changes in climatic elements and subsequently using these models for impact assessment of future climate change. The effect of technology on crop yield was segregated from weather to develop models of yield sensitivity to climate change. It involved first detrending the yield time series and then relating normalized yield deviations with monthly values of weather variables. These models were developed for major kharif and rabi crops grown in North West India and were used further for impact of future climate as per six IPCC SRES Scenarios for 2020, 2050 and 2080. The results show that in general, the rice and maize yield would be adversely affected by future climate whereas no significant impact would be there on wheat yield. The future climate is likely to be beneficial for sugarcane yield in this region.

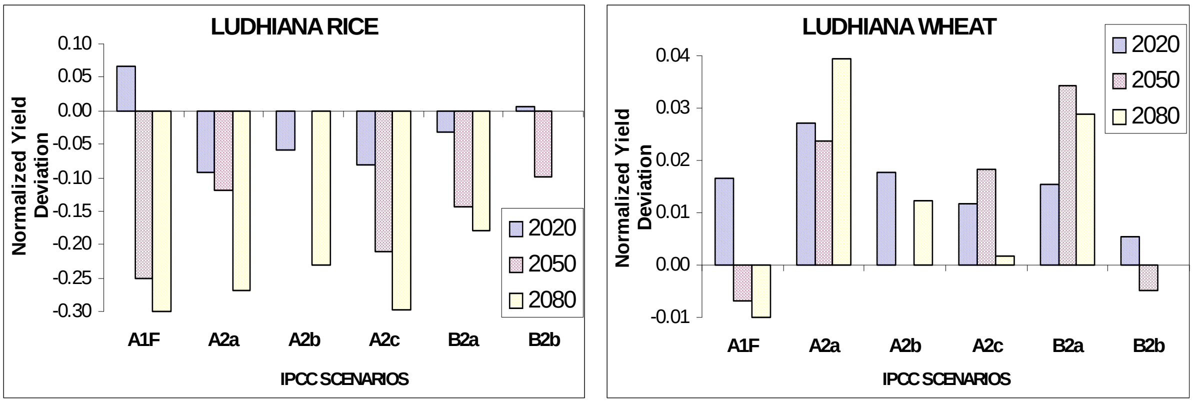



**Fig.2**. Impact of future climate change on rice and wheat yields at Ludiana

***Impact of high temperature on pollen sterility and pollen germination in rice***

Five different rice varieties (3 Basmati and 2 non-basmati cultivars) were sown at 12 different dates to observe the impact of temperature around flowering on pollen sterility and germination. Results showed that temperature around flowering stage has significant effect on fertility of the pollen grains. Tmax above 35°C and Tmin above 23°C increased pollen sterility in all the varieties. On the other hand pollen germination percentage on stigma decreased above 32°C of maximum day temperature (Fig. 3). Maximum percent of germinated pollen grains was found around 20°-25°C of minimum daily temperature. Temperature below and above this range decreased pollen germination in rice crop. Effect of high temperature on both pollen sterility as well as pollen germination percentage was more in basmati varieties as compared to non-basmati ones. Hence, high temperature around flowering will reduce fertility of the pollen grains and will affect grain formation and ultimately yield of the crop and this harmful effect is more profound in basmati cultivars.

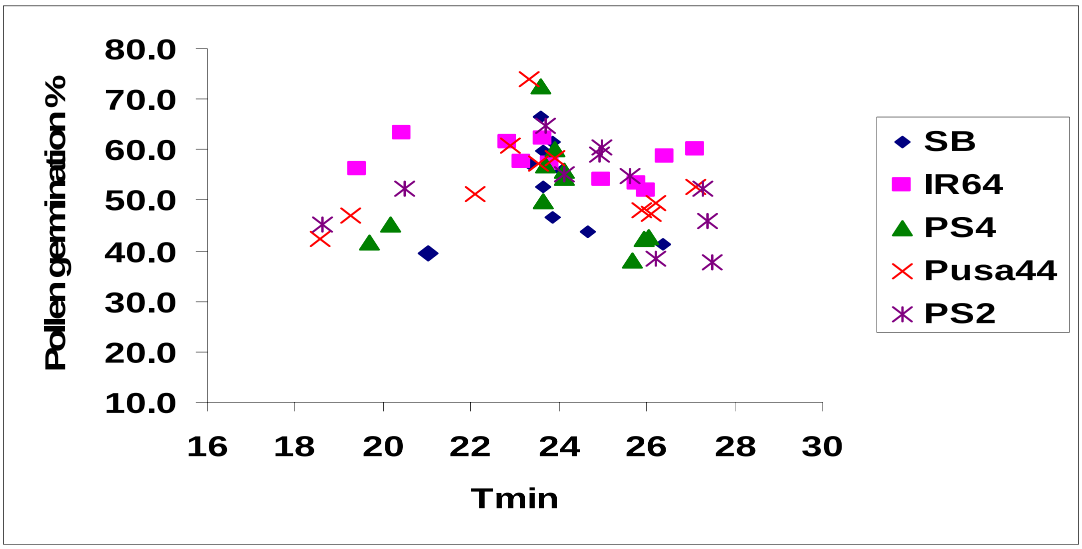



**Fig. 3.** Effect of daily maximum temperature on % pollen germination of rice.

***Interaction of high temperature and growth stages on sensitivity of rice varieties***

Aromatic (Pusa Sugandh 2) and non-aromatic (Pusa 44) genotypes were exposed to elevated temperature (+6$^0$C over the control) at different phonological stages to identify the most thermosensitive stage in rice. Plants kept under increased temperature (+6$^0$C over the control) for the entire growth period showed yield /plant comparable to the control indicating its adaptation under stressed environment. Both the genotypes were affected by increased temperature given at the reproductive phase and decrease in yield was attributed to increased spikelet sterility and reduced spikelet/panicle (Fig 4).

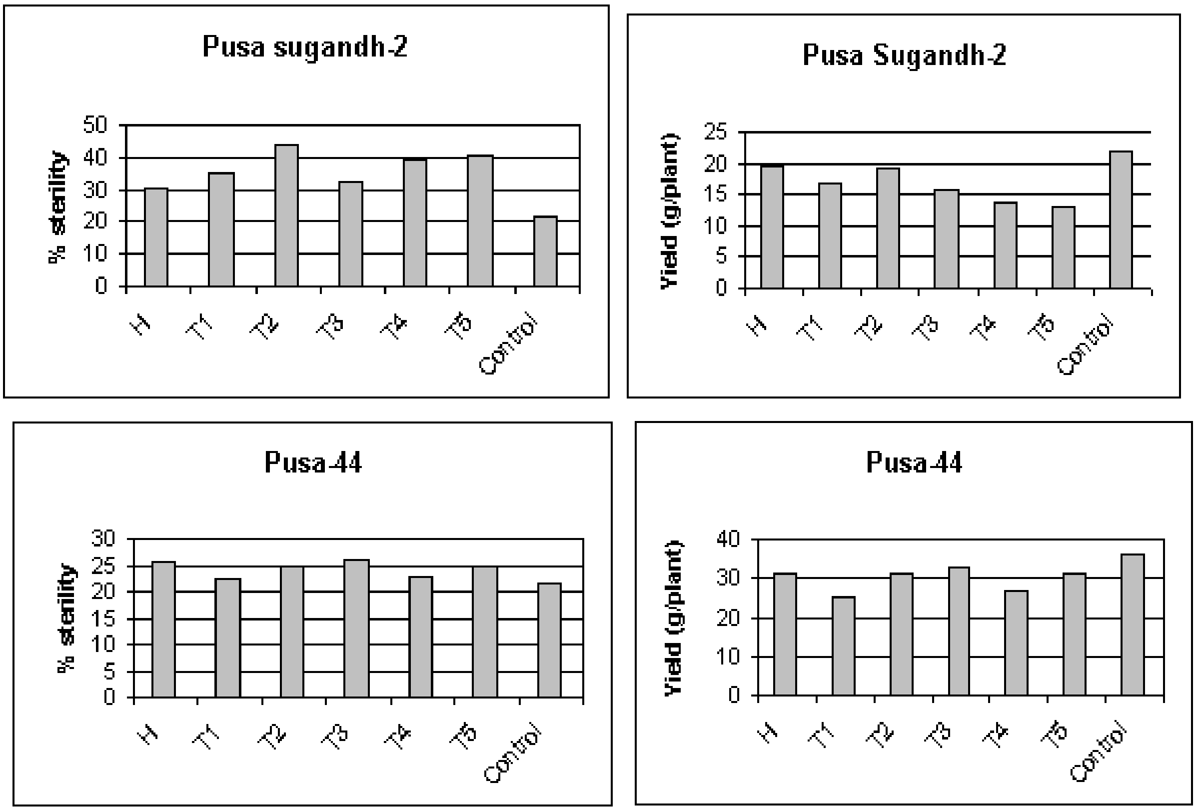



**Fig. 4.** Effect of high temperature exposure on yield and spiklet sterility in two rice varieties. T-Throughout crop growth, T1-Primordia initiation, T2-Panicle initiation, T2-Flowering, T3-Grain growth, T4-Control

**Effect of high temperature on rice productivity**

Two promising rice cultivars were grown under normal ambient and temperature gradient tunnels to assess the effect of elevated temperature throughout the growing season on their yield and yield attributes. Both the economic and biological yields were reduced drastically with elevated ambient temperature (Fig. 5). The degree of reduction in grain yield enhanced with rise in ambient temperature. The increase in thermal regime by 1, 2 and 3 $^0$C reduced the grain yield by 60, 64 and 70 percent in Pusa Sugandh 2 and 45, 52 and 54 percent in Pusa 44, respectively which was mainly attributed to maximum reduction in the number of panicles/m2 followed by the number of panicles /m2 and 1000 grain weight. Maximum extent of reduction in grains/panicle recorded in Pusa Sugandh 2 was mainly due to remarkable enhancement in its spikelet sterility. The harvest index and biological yield were also reduced significantly by increased temperature. Increased temperature (+1-3ºC) throughout growing period decreased the biological and economic yields by 32-37% and 60-70%, respectively in Pusa Sugandh 2, and 35-41% and 45-54%, respectively in Pusa 44. Amongst the rice cultivars, Pusa 44 proved to be more stable under warmer condition compared to Pusa Sugandh 2.

**Pusa Sugandh-2** **Pusa-44**

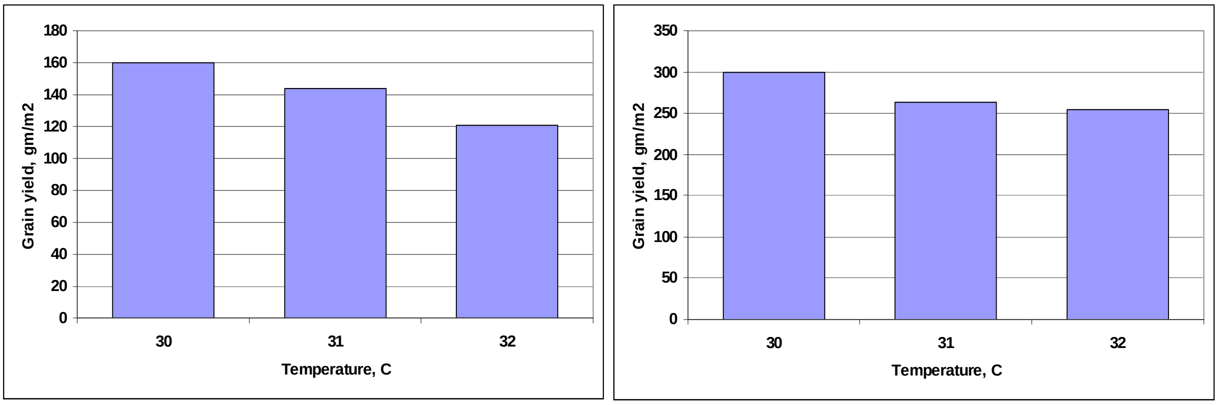



**Fig 5.** Impact of increased temperature on yield of two rice varieties.

***Impact of growing environment on grain quality traits of rice***

The harvested grains of the previous experiment was evaluated for quality in terms of test weight, proportion of high density grain, length-breadth ratio of grain before and after cooking, amylose content, gelatinization temperature and aroma of basmati cultivars. The changes in these traits with respect to different temperature regimes during grain growth period was evaluated. The results showed that the test weight declined by about 2g in all cultivars as the temperature during grain growth increased from 24 to 31$^0$C. Proportion of high density grain was found to be a stable parameter within the temperature range tested. The ratio of length and breadth of un-cooked and cooked grain exhibited second order polynomial relation with mean temperature and their values decreasing at both high (>30$^0$C) and low temperatures (<24$^0$C). Both aromatic and non-aromatic varieties exhibited maximum linear elongation of cooked rice within the temperature range of 24 to 28$^0$C (Fig.5). Amylose content of grain decreased linearly with increase in mean temperature. This decline varied from 0.6% per degree rise in temperature in IR-64 to 0.2% P. Sugandh-4 (Fig.6).

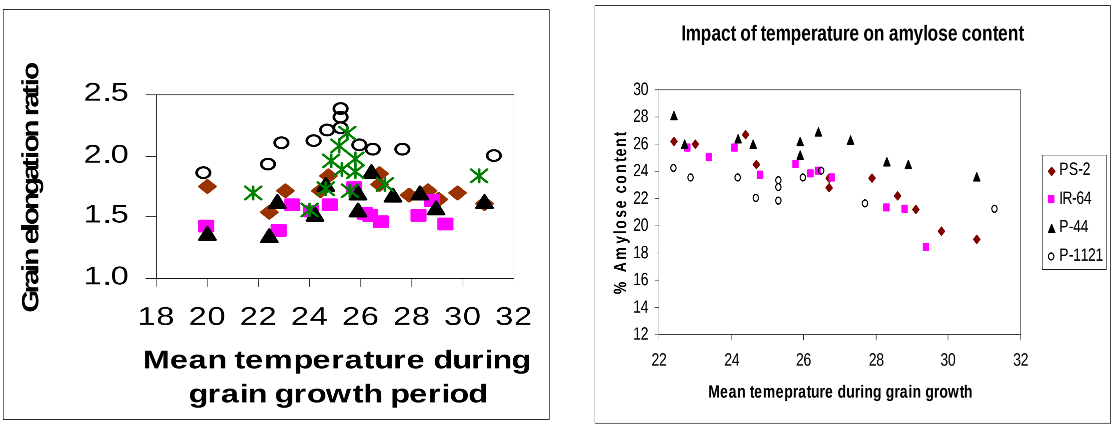



**Fig. 6.** Relationship of (a) grain elongation ratio after cooking and (b) amylase content with mean temperature during grain growth period.

Gelatinization temperature increased at temperatures above $30^0$C in P. Sugandh-2 and IR 64 and was stable in other cultivars. Aroma in basmati type cultivars (P. Sugandh-2 & 4, Super Basmati) declined drastically when the mean temperature during grain development increased above $25^0$C in photo-sensitive cultivars and above $27^0$C in photo-insensitive cultivars.
The study revealed that the prevailing temperature regimes during grain development phase of rice affect their quality and the impact varies with cultivar and its sensitivity to photoperiod. The quantification of the impact will be useful in planning for future climate change scenarios.

***Impact of elevated $CO_2$ and temperature on rice***

Two rice genotypes, Pusa Sugandh-2 and Pusa-44 were grown in the open top chambers with four treatments consisting of two temperature levels and two $CO_2$ concentrations. Irrespective of $CO_2$ levels, at higher temperature there was decrease in photosynthesis, total dry matter production and seed yield. Pusa 44 showed a higher response to temperature and $CO_2$ changes in terms of dry matter production and seed yield (Fig. 7). It also showed a lower level of spikelet sterility as compared to P.Sugandh-2. The stomatal conductance and transpiration rate decreased with elevated $CO_2$ and lead to higher photosynthetic water use efficiency. However under elevated $CO_2$ levels along with elevated temperature there was increase in stomatal conductance and transpiration rate that reduced it. It is therefore concluded that increase of temperature by 1-4$^o$C can override the beneficial effect of elevated $CO_2$ on photosynthesis, dry matter production, seed yield and photosynthetic water use efficiency.

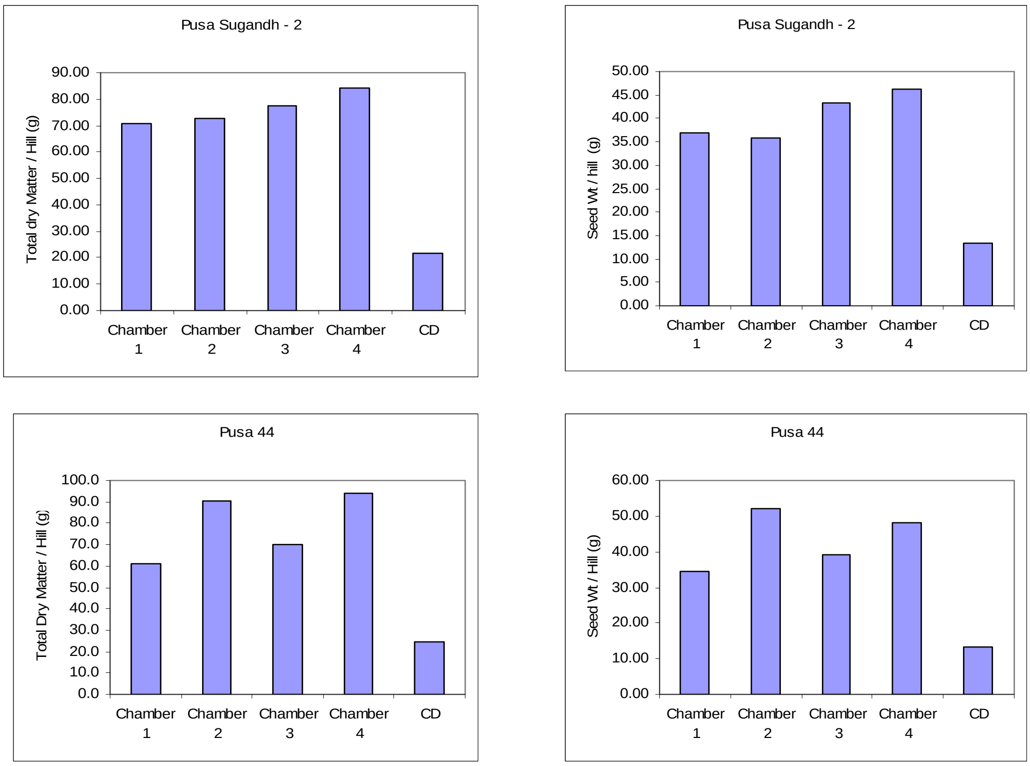



**Fig 7.** Effect of elevated $CO_2$ and temperature on the dry matter production and seed yield in two rice cultivars. Chamber 1: Elevated Temp.+ Elevated $CO_2$; Chamber 2: Ambient Temp. + Elevated $CO_2$ ; Chamber 3: Elevated Temp. + Ambient $CO_2$

***Impact of high temperature at various growth phases on biomass and yield of wheat, chickpea, mustard and potato***

Four important Rabi crop species viz., wheat, chickpea, mustard and potato were grown in field and subsequently subjected to high thermal stress from sowing to maturity and flowering to maturity using poly chamber and also to normal ambient condition to examine the vulnerability/sensitivity of different phenophases of these crops to high thermal stress. It is evident from the results that high thermal stress (+3.5 0C) from germination to maturity caused 42% reduction in grain yield of wheat, 93 % in seed yield of mustard and 40% tuber yield in potato, while heat stress imposed during post flowering duration manifested 18, 60 and 12 percent reduction in economic yield of wheat, mustard and potato, respectively. The reduction in economic yield of wheat by heat stress was mainly attributed to marked reduction in the number of spikes/m2, grains/spike and 1000grain weight and biomass. Harvest index of wheat was least affected by heat stress. However, reduction in economic yield was mainly due to marked reduction in the number of plants and biomass per unit land area and harvest index in mustard and number of tubers/m2 in potato (Fig.8).

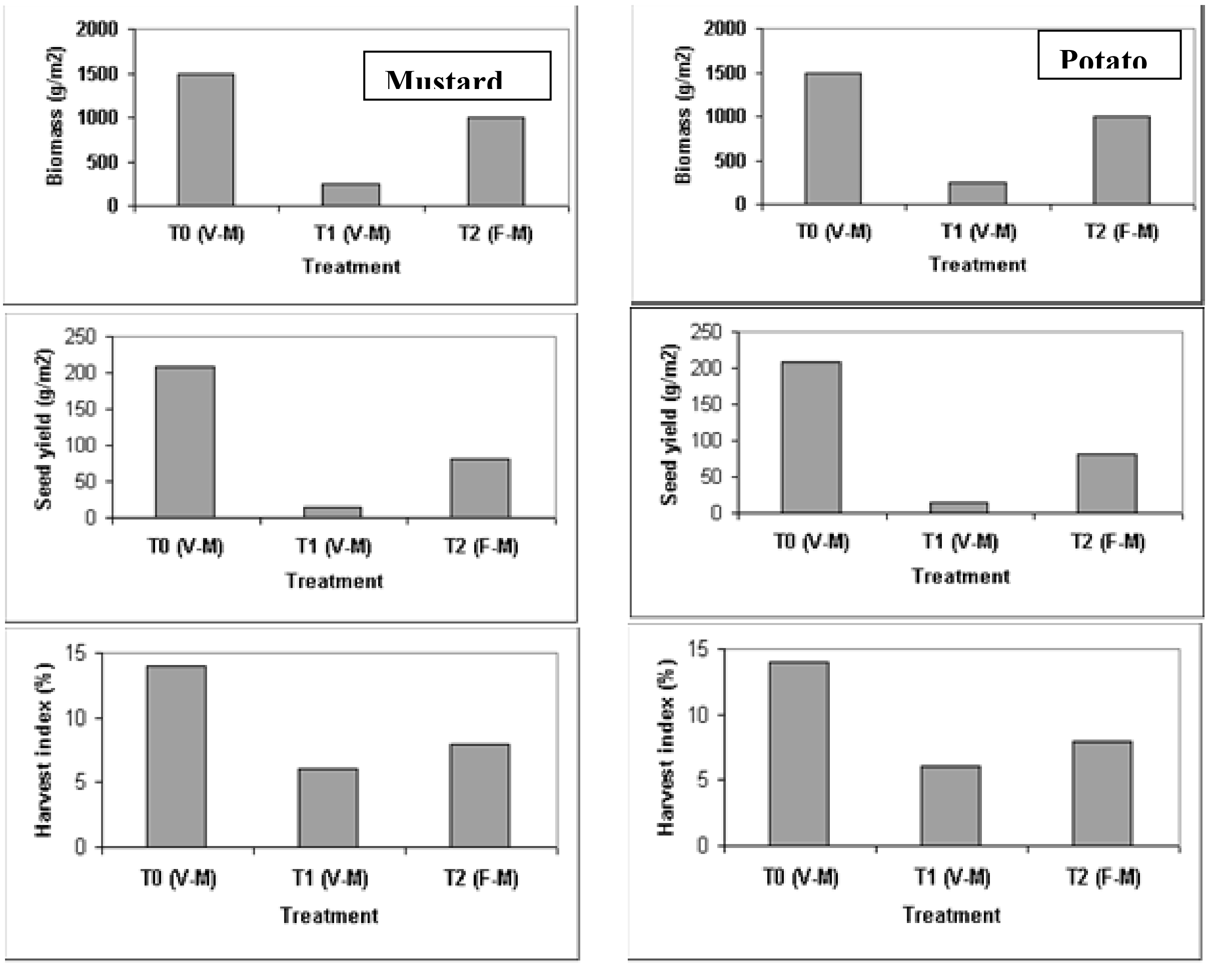



**Fig.8**. Effect of high temperature on yield of mustard and potato crops. T0: Normal ambient temperature; T1: high temp from germination to maturity; T2: high temperature from flowering to maturity

**Relationship between biophysical parameters and performance of wheat under late heat condition**

In a field experiment, 15 bread wheat and 5 durum wheat varieties were exposed to late heat by delayed sowing and their performance was compared to normal sowing. The susceptibility Index (SI) calculated as yield decrease due to stress relative to potential yield was higher for durum wheat compared to bread wheat. The relationship between mean yield and SI values showed that the genotypes like HD 2923, WR 1508, PBW 175 and Kundan were adapted to late heat stress as they combined low SI with high yields.

Biophysical parameters such as leaf membrane stability index (MSI), Canopy temperature depression (CTD) and leaf water Spin-lattice relaxation time T1 were measured and related to SI values (Fig. 2-4). High correlation between SI values and MSI (r=0.569**), CTD (0.686**) and leaf water T1 (r=0.724**) indicated that these traits could be used as selection criterion for adaptation to temperature stress in wheat.

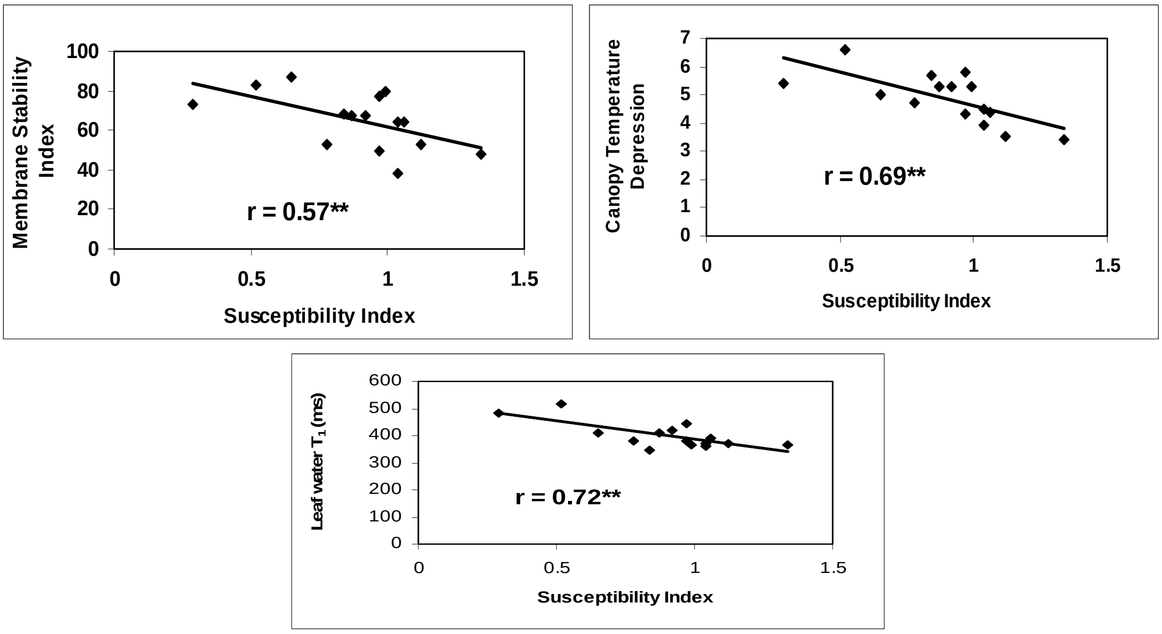



**Fig. 9**. Relationship between biophysical parameters and Susceptibility Index for grain yield of 20 wheat genotypes under late sown conditions.

**Impact of temperature on pollen sterility and pollen germination in wheat**

Pollen viability and germination of pollen grains on stigma is a temperature sensitive physiological process which ultimately controls grain formation and crop yield. Field experiment was conducted with 5 different wheat varieties (3 aestivum & 2 durum) to study the impact of temperature on pollen sterility in wheat crop. Those varieties were sown at 9 different dates. As a result anthesis occurred at varying dates & the crop was exposed to different temperatures during the period of anthesis. Wheat varieties (HD 2851 & HI 8498) where anthesis took place earlier (Dec & Jan) showed higher pollen sterility percentage as compared to others. In early dates of planting when mean temperature was lower HD 2936 also recorded higher pollen sterility as compared to the later dates.

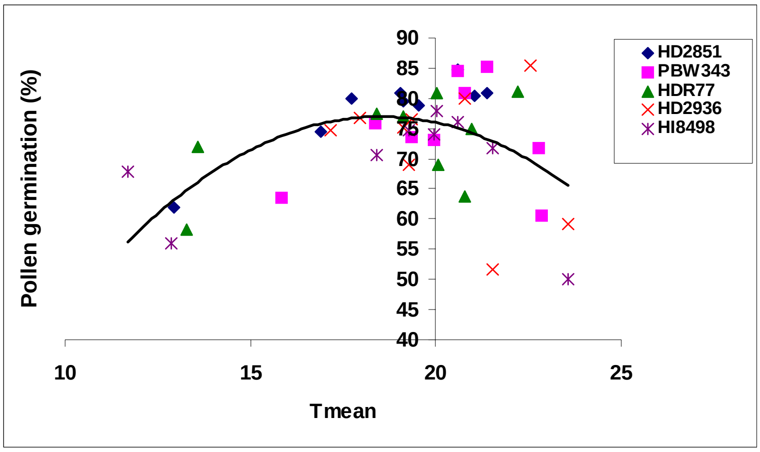



**Fig. 10. Impact of temperature on pollen germination in different wheat varieties**

Pollen germination percentage on stigma was found to increase with increasing temperature. When temperature was below 16°C pollen germination was less in all the wheat cultivars. More than 80% of the pollens deposited on stigma germinated in all the varieties when mean temperature varied between 17°C-22°C (Fig. 10). Maximum pollen germination (85.4%) was found in HD 2936 followed by PBW 343 (85.2%) at 22.5 and 21.4 degrees respectively.
This study shows that sudden fall in temperature during the rabi season will prove to be detrimental for the wheat crop. Besides this durum varieties (HI 8498 & HD 2936) were more susceptible to temperature fluctuations as compared to aestivum cultivars.

**Effect of heat stress on growth and yield of wheat**

Two promising wheat cultivars namely HD 2329 and PBW 343 were sown from 15$^{th}$ October to 15$^{th}$ January at fortnight interval to examine the effect of early and late heat stress on growth, yield and yield contributing characters. High ambient temperature both during early and late sown conditions caused reduction in growth, yield and yield components of both the cultivars. The reduction in growth and yield of wheat by delayed sowing was attributed to marked reduction in plant height, leaf area index, days to flowering, maturity duration, number of spikes/m2, grains/spike, biological yield, while 1000 grain weight and harvest index were least affected by delayed sowing. Grain yield of both the cultivars reduced around 40% by 5 $^{0}$C increase in seasonal mean temperature (Fig 11.). Higher thermal regimes only during late sowings caused gradual reduction in days to flowering as well as maturity durations in both medium (HD 2329) and long (PBW 343) duration cultivars as high temperature in early sowing (15$^{th}$ Oct.) could not reduce flowering and maturity durations.
Among the cultivars, the medium duration cv. HD 2329 showed greater growth and yield stability to heat stress as compared to long duration cv. PBW 343.

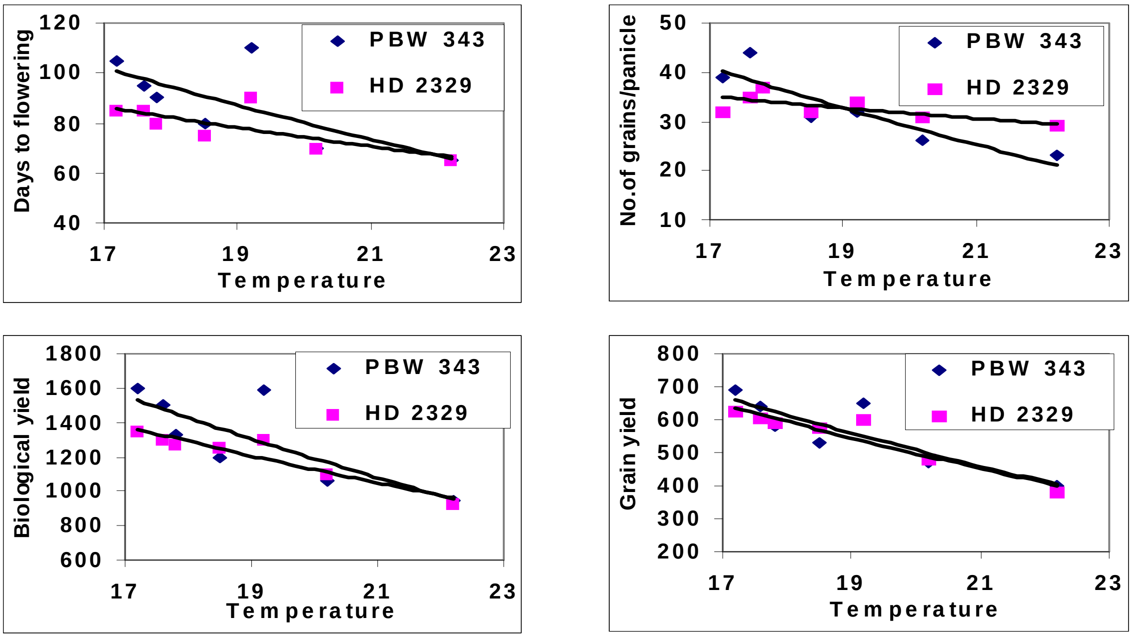



**Fig 11.** Impact of increase in temperature on wheat yield attributes

***Impact of different temperature regimes on yield and quality of bread wheat and durum wheat cultivars***

A field experiment was conducted with two bread wheat (HDR 77 & PBW 343) and two durum (HD 2936 & HI 8498) cultivars with fortnightly to expose the crop to varying temperature regimes during vegetative and reproductive periods. In general, the number of ears/m$^2$ was greater for bread wheat varieties compared to durum wheat and declined by more than 50%, as the mean temperature during vegetative phase (sowing to anthesis) increased beyond 18$^0$C. The decline in biomass beyond 18$^0$C was compensated by increase in harvest index. A narrow range of mean season temperature of 17 to 20$^0$C was found optimum for grain yield in both species. Temperatures beyond 25$^0$C reduced hectolitre weight by 5-8 units in both bread wheat varieties and in one durum variety. Durums showed stable values than bread wheat. Protein content increased almost linearly with increase in mean temperature during grain growth period (Fig. 12). The β-carotene in durum varieties remained between 4 and 5 ppm throughout the temperature range of 16-29$^0$C indicating its stability against temperature changes.

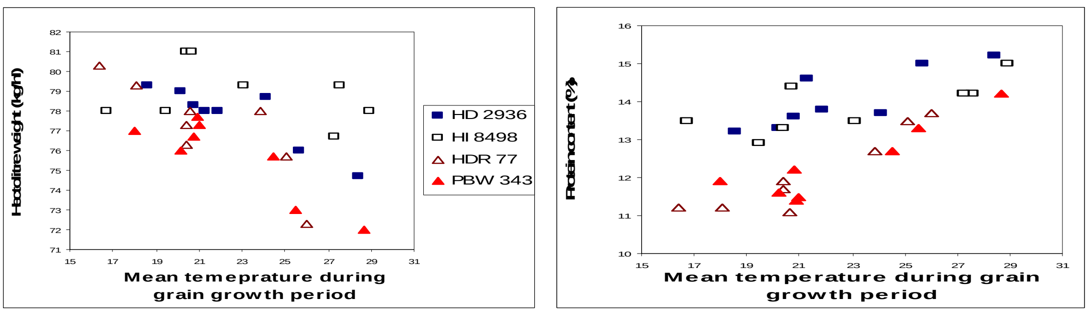



**Fig.12** Impact of mean temperature during grain growth on hectolitre weight and protein content of grain in wheat.

The study showed the temperature limits for optimal growth, yield and quality traits for two bread wheat and durum cultivars. Thus, the quantification of impact of growing environmental temperatures on yield and quality parameters will help in developing ideal plant type for future climatic scenarios.

***Impact of elevated $CO_2$ on growth and yield of chickpea cultivars***

Chickpea cultivars varied greatly in their response to elevated $CO_2$ as the cultivar Pusa 1108 responded better and exhibited appreciable increase in growth and yield characters as compared to Pusa 1053. In Pusa 1108, under elevated $CO_2$, there was an increase of 26 % in shoot biomass, 22% in number of grains per plant. The effect of high $CO_2$ exposure on total grain weight per plant was not significant in either cultivar. 100 grain weight remained unaffected in Pusa 1053 due to high $CO_2$ treatment and in Pusa 1108 it showed marginal reduction of about 5 %. This study suggest that enhancement in growth and all the yield characters in Pusa 1108 might be due its better and efficient sink capacity for utilization of extra carbon assimilates fixed by the plants under high $CO_2$ environment.

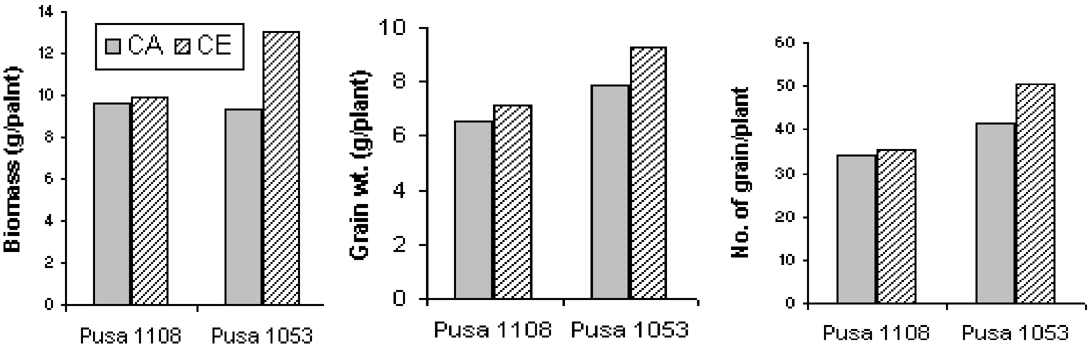



**Fig. 13 .** Effect of elevated $CO_2$ on growth and yield of two chickpea cultivars.
CA-Ambient $CO_2$ (370µl $l^{-1}$), CE-Elevated $CO_2$ (550µl $l^{-1}$)

***Impact of climate change scenarios on chillo partellus***

Maize stem borer, *Chilo partellus* rearing on artificial diet was successfully done. Under the controlled condition *i.e*. at 30°C, 32.5°C and 35°C, fecundity, incubation period and survival percentage of this pest at different developmental stages was worked out. At 37°C and onward mean fecundity, and survival of eggs drastically reduced (at 37°C and 38°C fecundity reduced to 62 and 42 while survival was nil). Sex ratio was also found to be 2:1 (male: female) when normal pupa kept above 37°C.

On the basis of functional model developed on fecundity and climate change scenario of 2050, it was concluded that in general most places in India might show some decrease in fecundity of Chillo (Fig.14).

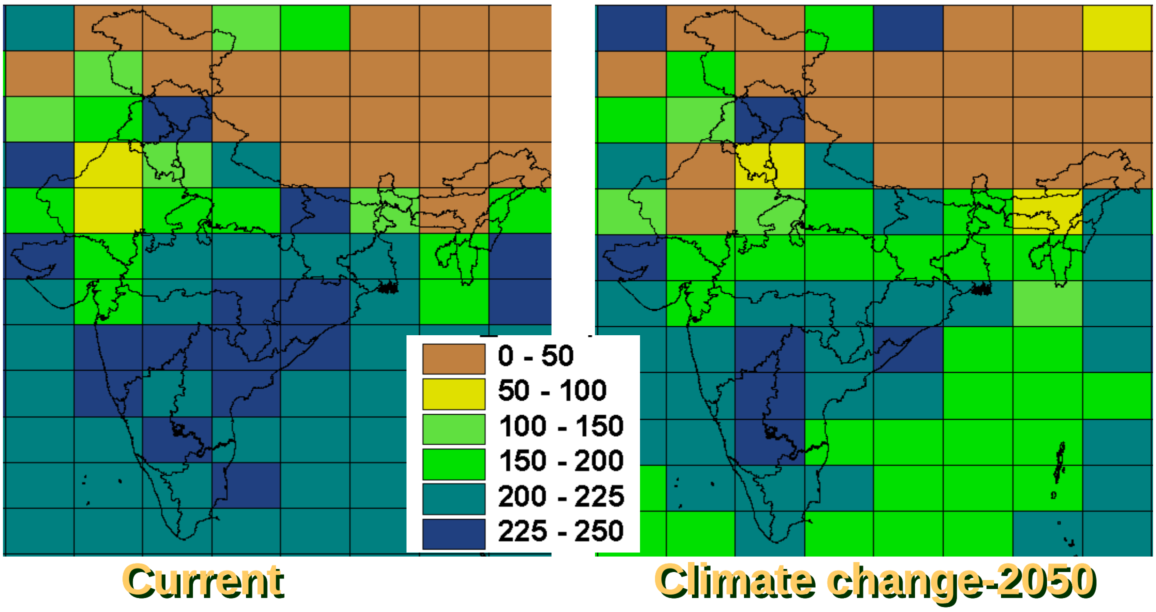



**Fig.14** Change in the fecundity of *Chillio partellus* with climate change scenario of 2050.

***Soil Carbon dynamics: Impact of temperature on different soil types***

The response of soil respiration in terms of turnover time, their temperature sensitivity as measured by $Q_{10}$ and the amount of labile and recalcitrant carbon pools representing sites with low carbon i.e. Kerala (oxisol, 0.34% organic carbon), medium carbon (Jabalpur vertisol, 0.51% organic carbon; Delhi, 0.56% organic carbon, Inceptisol) and high carbon i.e. Dehradun 1.05%, organic carbon, Alfisol; Pantanagar, 1.83% organic carbon Molisol) was carried out by soil incubation studies to identify the sensitivity of Indian soils to predicted climate changes in different physiographic regions viz. coastal plains, Peninsular India and the Great Plains.

The turnover times for low and high carbon soil were more sensitive in the region of + 5 $^0$C mean annual temperature. (Fig15.) However, the medium carbon soils showed uniform pattern of decomposition with increase in temperature. However, $Q_{10}$ initially increases and then declines after the optimum temperature in a predictable manner in high carbon (OC > 1.0 %) and low carbon scenario (OC, <0.5%), whilst it remained constant in soils with medium carbon (OC, 0.5-1.0 %). Soil warming experiments a proxy for the effects of global warming on soil organic matter decompositions suggest that the decline in the low and high carbon soils after the optimum temperature may be due to the significant difference of resistant carbon from the labile carbon pool which is insensitive to temperature variation.

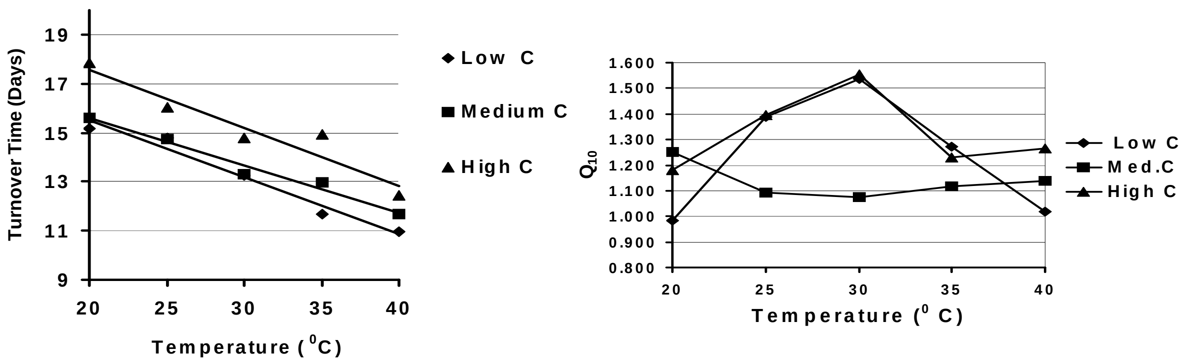



**Fig 15.** Estimation of turnover times for low, medium and high carbon soils of India and The $q_{10}$ of $CO_2$ efflux from soil as a function of temperature.

***Dynamics of soil microbial community in response to temperature in different soil carbon scenarios***

The changing climate will influence the above-ground plant and ecosystem processes directly by effect of elevated $CO_2$ on productivity and by indirect effect of temperature on soil biota and their activities. This study examined the effects of elevated atmospheric temperature on the microbial community composition in low, medium and high carbon soil scenarios. The shift in the microbial community composition as measured by phospholipids fatty acid analysis (PLFA) was studied by incubating the low carbon i.e. Kerala (oxisol, 0.34% organic carbon), medium carbon (Jabalpur vertisol, 0.51% organic carbon; Delhi, 0.56% organic carbon, Inceptisol) and high carbon i.e. Dehradun 1.05%, organic carbon, Alfisol; Pantanagar, 1.83% organic carbon Molisol) at different temperatures. In total, 26 different PLFAs were classified as indicators for special microbial groups in the Community. The change in relative abundance of fungal PLFAs was determined by using 18:2ω6 PLFA for fungi. The sum total of all the aforementioned biomarkers was used for calculation of total PLFA. Microbial community composition was significantly influenced by temperature x carbon interaction. Total PLFA content in high carbon soil increased significantly from 76 nmol $g^{-1}$ to 311nmol $g^{-1}$, when the temperature was increased from 20 to 25 $^0$C (Fig. 16) and further increase in the temperature just lead to the stabilization in the microbial biomass as determined by the PLFA. Our study demonstrates the shift in microbial communities growing under elevated temperature, thereby indicating altered rates of microbial metabolism in carbon mineralization.

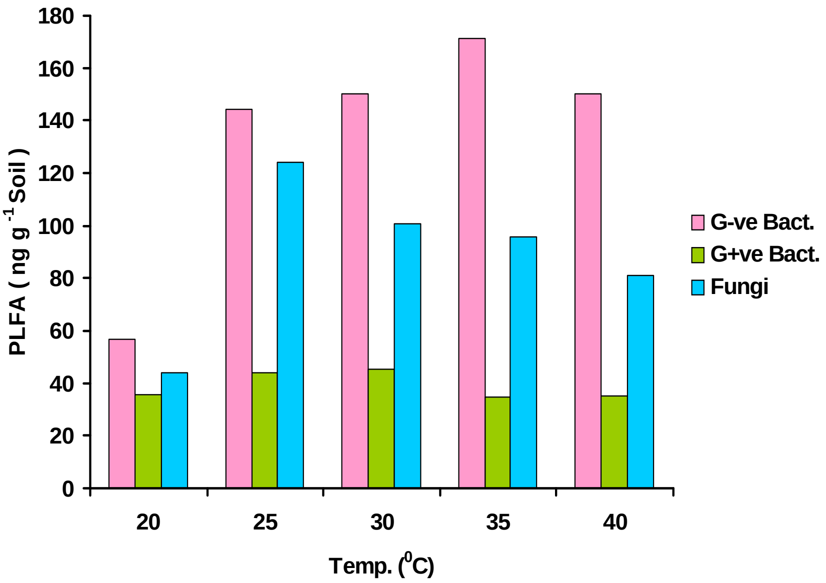



**Fig 16.** Impact of temperature on soil microbial community structure

***Quantification of global warming potential of agricultural soils in different agro-ecological zones using Infocrop model***

A spatial inventory of $N_2O$, and $CO_2$ emission from the wheat growing areas in different agro-ecological zones of India was prepared. Soil, management and climatic parameters were collected for 94 agro-ecological zones of India. Agro ecological zone specific emission coefficients of the $N_2O$, and $CO_2$ emission were simulated using Infocrop model. The Global warming potential of the soil area under wheat was also determined. The total annual emission of the GHGs and the GWP was then spatially mapped. The total annual emissions from 27.4 million ha of wheat fields were 17.10 Gg and 43.20 Tg of $N_2O$-N and $CO_2$-C, respectively, with a cumulated GWP of 164 Tg $CO_2$ equivalent. The total GWP of soils under wheat was 48% lower than the GWP of rice soils (Fig.17).

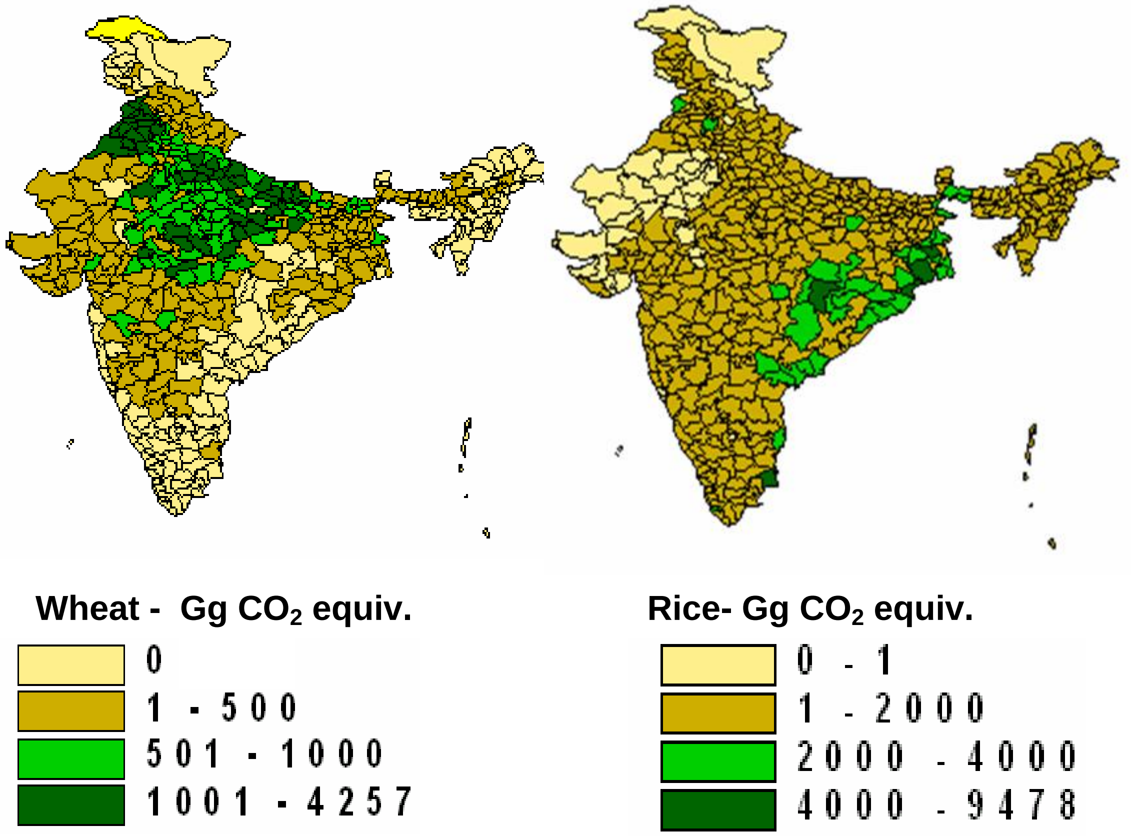



**Fig. 17:** Global Warming Potential (GWP) of Soils under Rice and Wheat

**Quantification of Sources and sinks of GHGs**

The methane emission subroutine of Infocrop crop growth simulation model was validated in six agro-ecological regions of India. The methane emissions in the major rice ecosystems of rain fed, irrigated lowland and irrigated upland conditions were simulated. The simulated emissions were at par with the observed emissions (Table 1.). The model performed well in different fertilizers treatments including the use of organic amendments like farmyard manure. The deviation of simulated from observed varied from 0.1 to 26%.

**Table 1. Emission of methane in different Agro-ecological regions using Infocrop model**

| Location | Year | Irrigation | Inorganic Fertilizer (Kg N $ha^{-1}$) | Observed Methane (Kg $ha^{-1}$) | Simulated Methane (Kg $ha^{-1}$) |
|---|---|---|---|---|---|
| Cuttack | 1996 Kharif | Rainfed | 60 | 43 | 38 |
| | 1998 Rabi | Continuous Flooding | 120 | 70 | 66 |
| Karnal | 1998 Kharif | Continuous Flooding | 120 | 79 | 76 |
| | | | | 106 | 83 |
| Trivandrum | 1998 Kharif | Intermitent Flooding | 60 | 36 | 28 |
| Chennai | 1998 Kharif | Continuous Flooding | 120 | 160 | 150 |
| | | | 60 + 60* | 188 | 171 |
| Pant Nagar | 1998 Kharif | Continuous Flooding | 120 | 71 | 76 |
| | | | 60 + 60* | 125 | 105 |
| | | Intermitent Flooding | 120 | 54 | 56 |
| | | | 60 + 60* | 72 | 73 |
| Gabberria, South 24 Paraganas | 1998 Rabi | Continuous Flooding | 120 | 145 | 138 |
| | 1998 Kharif | Continuous Flooding | 120 | 430 | 318 |

***Impact of tillage management on global warming potential (gwp) of soils under rice-wheat cropping***

Emission of Green House Gases (GHGs) is responsible for climate change. To quantify the effect of tillage and organic matter on emission of green house gases, a field experiment was conducted with rice and wheat crops. There was a 15% decrease in the GWP in the urea and urea +FYM treatment under no tillage conditions in the wheat. The $CO_2$-C emissions decreased by 19 % and $N_2O$-N emissions increased by 13% in no till urea treatment as compared to conventional tillage in wheat. In rice a 10% increase in GWP was observed in urea+FYM treatment (Table 2). Significant decreases in yields were observed in both no till wheat and non-puddled rice. The emission of $N_2O$-N increased by 12-24%, $CO_2$-C emissions decreased by 8-11% and there was no significant impact on emission of $CH_4$ in non-puddled rice soil.

**Table 2.** Impact of No Tillage (NT) on emission of Greenhouse gases

| Year | % Decrease in $CO_2$ in NT over CT | | % Increase in $N_2O$ in NT over CT | | % Decrease in GWP in NT over CT | |
|---|---|---|---|---|---|---|
| | Urea | U+FYM | Urea | U+FYM | Urea | U+FYM |
| **Kharif 2004** | 5 | -7 | 14 | -2 | 3 | -6 |
| **Kharif 2005** | 8 | 11 | 8 | 10 | 6 | 2 |
| **Rabi 2004** | 10 | 16 | 14 | -7 | 7 | 18 |
| **Rabi 2005** | 25 | 18 | 20 | 6 | 19 | 16 |

***Impact of climate change on yield loss in wheat crop***

A simulation study was carried out to quantify the impact of increase in temperature and $CO_2$ on yield loss of wheat. Results revealed that increase in temperature will increase yield loss of wheat crop. With same temperature increase yield loss will be less under higher CO2 concentration (Fig 18). From this study it can be predicted that in 2020, with temperature increase of 1ºC and 450 ppm CO2 concentration there will be an yield loss of around 5 million tones.

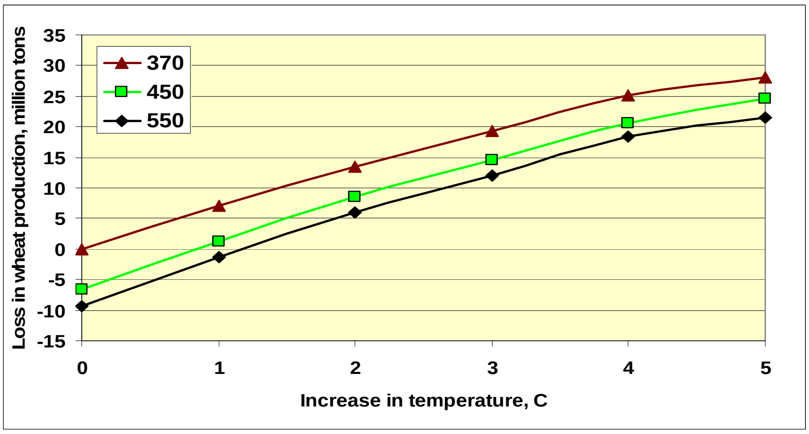



**Fig 18. Loss in wheat yield due to climate change**

If farmer's adapt to the changing environment then yield loss may be prevented to certain extent. But with more increase in temperature this adaptation benefit gradually decreased (Fig 19).

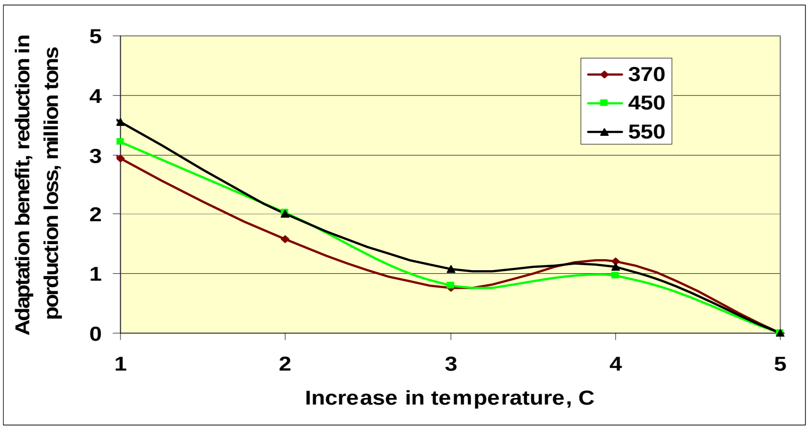



**Fig 19. Loss reduction in wheat if farmers adapt**

**Trade-off between global warming potential and food production**

To understand the magnitude of improvement in food production, and its linkage with the input management and its consequence on emissions of greenhouse gases and associated global warming potential, a simulation experiment was done for the lowland rice at Faizabad in Eastern India. The control crop was provided with 80 kg N $ha^{-1}$ fertilizer, intermittent irrigation and no organic matter to mimic the current agronomic environment. Eight other treatments were also simulated where additional nutrient application of 80 kg N $ha^{-1}$ was made as either inorganic or as organic (farmyard manure) source. Interaction of these nutrient applications with two irrigation treatments- a) continuous flooding and b) irrigation applied to maintain soil moisture at field capacity, were also simulated.

The control crop, with intermittent irrigation and modest inorganic fertilizer application, yielded 3335 kg $ha^{-1}$. Each kg of this production required 13.04 mm of water and resulted in a global warming potential equivalent to 0.37 kg of $CO_2$. Continuous flooding increased grain yields by 33% but resulted in a substantial decrease in the water use efficiency and a large (50%) increase in global warming potential (Table 3). If the fields were not flooded but maintained at field capacity the yields were similar but there was substantial saving in irrigated water used and only a very modest increase in the global warming potential.

Grain yields also increased by the additional inorganic fertilizer even at the intermittent irrigation level indicating that yields were limited by both water and nutrient availability. As a consequence the water use efficiency was slightly improved and the global warming potential marginally increased at all irrigation levels. When organic matter was added to increase nutrient availability the grain yields increased as much as that by inorganic fertilizer alone. This did not require any significant additional water and hence the water use efficiency of the two treatments was similar. However, there was almost a 2-3 times increase in the emissions of greenhouse gases and hence the global warming potential at all irrigation levels. Thus, it is clear that to meet the future rice demand from Eastern India scientific irrigation practices are needed and, if global warming potential of agriculture remains an issue, care is needed in organic matter additions.

**Table 3.** Simulated grain yields, irrigation water used, and global warming potential of different treatments of rice contrasting in inorganic/organic fertilizer management and irrigation.

| Inorganic N, kg/ha | Organic matter, kg/ha | Irrigation | Grain yield, kg $ha^{-1}$ | Irrigation, mm | Global warming potential, kg $CO_2$ $ha^{-1}$ | Carbon efficiency, gm $CO_2$ $kg^{-1}$ grain | Water use efficiency, Grain yield $mm^{-1}$ water used |
|---|---|---|---|---|---|---|---|
| 80 | 0 | Intermittent | 3335 | 256 | 1239 | 371 | 13.04 |
| 80 | 0 | Based on soil moisture | 4212 | 729 | 1608 | 382 | 5.78 |
| 80 | 0 | Continuous flooding | 4475 | 1676 | 1882 | 421 | 2.67 |
| 160 | 0 | Intermittent | 4241 | 269 | 1384 | 326 | 15.79 |
| 160 | 0 | Based on soil moisture | 4913 | 754 | 1746 | 355 | 6.51 |
| 160 | 0 | Continuous flooding | 4966 | 1684 | 2014 | 406 | 2.95 |
| 80 | 80 | Intermittent | 4145 | 264 | 3235 | 780 | 15.68 |
| 80 | 80 | Based on soil moisture | 4937 | 754 | 4800 | 972 | 6.54 |
| 80 | 80 | Continuous flooding | 5139 | 1689 | 5679 | 1105 | 3.04 |

# Central Plantation Crop Research Institute

**1. Infrastructure facilities established**

OTC facility for elevated $CO_2$ and temperature is established with SCADA based auto-controlling system.

Plate 1: OTC facility at CPCRI

Apart from this the all other equipments are procured.

***Recent trends in weather, climate, production and productivity of coconut and pepper***

The analysis of past weather data from different locations representing the major coconut and pepper growing agro-climatic zones and yield data from the respective districts indicated following trends.

**Table 1:** Past trends in weather and productivity in coconut growing areas in India

| Centre | Temperature | | DT | >33 oC days | < 15 oc days | RH changes | Rainfall | | | Overall change | Dry spell | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | | | | | Annual | intensity | Days <2.5 mm | | | |
| Ratnagiri (MS) | ↑ | ↓ | ↑ | ↑ | nil | ↓ (RH Max) | ↑ | ↓ | ↑ | Cool N Warm D Dry | ↓ | ↑ |
| Mulde (MS) | ↑ | ↑ | ↑ | ↑ | ↓ | ↑ | ↓ | ↓ | ↓ | Warming | ↓ | ↑ |
| Arsikeri (Kar.) | ↑ | ↓ | ↑ | ↑ | ↑ | ↓ (RH max) | ↓ | ↑ | ↓ | Cool N Warm D Dry | ↔ | ↓ |
| Kidu (Kar) | ↑ | ↑ | ↓ | ↑ | ↓ | NA | ↓ | ↑ | ↑ | Warming | ↑ | ↓ |
| Kasaragod (Ker) | ↑ | ↓ | ↑ | ↑ | ↑ | ↑ | ↓ | ↓ | ↑ | Cool N Warm D | ↑ | ↑ |
| Trissur (Ker) | ↓ | ↔ | ↓ | ↓ | nil | ↔ | ↓ | ↑ | ↓ | RF Dis. changing | ↓ | ↑ |
| Trivendrum (Kerala) | ↑ | ↑ | ↑ | ↑ | nil | NA | | ↓ | ↓ | Warming | ↑ | ↑ |
| Aliyarnagar (TN) | ↑ | ↓ | ↑ | ↑ | ↑ | ↑ RH min | ↓ | ↓ | ↑ | Cool N Warm D | ↓ | ↓ |
| Veppankulam (TN) | ↑ | ↑ | ↑ | ↑ | nil | ↓ RH min | ↓ | ↑ | ↓ | Warming | ↑ | ↑ |
| Ambajipeta (AP) | ↑ | ↑ | ↓ | ↑ | ↔ | ↑Min RH | ↓ | ↓ | ↑ | Warming | ↓ | ↑ |
| Calcutta (WB) | ↓ | ↓ | ↓ | ↓ | ↓ | NA | ↓ | ↓ | ↑ | Cooling | ↓ | ↑ |

**Table 2:** Past trends in weather and productivity in major pepper growing areas in India

| **Place** | **Rain fall** | **Tmax** | **Tmin** | **Productivity** |
|---|---|---|---|---|
| KERALA - Wynad | Decreasing | Increasing | Increasing | Decreasing |
| Calicut | Decreasing | - | - | Decreasing |
| Cannanore | Decreasing | Increasing | Increasing | Decreasing |
| Tamil Nadu -Valparai | No trend | No trend | Decreasing | No trend |
| Nilgiris | Increasing | Increasing | No trend | Decreasing |
| Karnataka - Coorg | Decreasing | - | - | Decreasing |

***Extreme events in weather/climate and effect on coconut yield: Droughts and cyclone***

In order to study the impact of climate change related events like cyclones and droughts, the data was analyzed. Consecutive drought years in Coimbatore district of TN and Tumkur District of Karnataka, caused not only drastic reduction in yield but also about 6 lakhs of palms were died in both districts. In Godavari districts of AP cyclone of 1995 badly affected the coconut yields. The yields drastically reduced in 1995-96 and then it took four to five years for the recovery of affected gardens. The details are presented in below.

**Fig 2**: Loss in coconut yields in Coimbatore Dist due to droughts

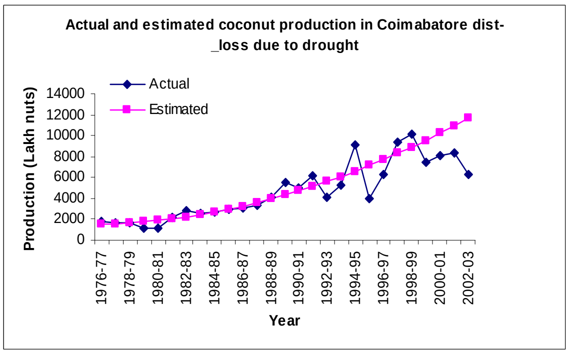



**Table 3:** Coconut production loss in Coimbatore dist (TN) due to consecutive droughts

| Year | Loss in production due to drought (Lakh nuts)<br>Coimbatore dist |
|---|---|
| 1999-00 | -2145 |
| 2000-01 | -2129 |
| 2001-02 | -2661 |
| 2002-03 | -5379 |
| Total loss (lakh nuts in 4 years) | -12313 |
| Loss (lakh nuts)/year | -3078 |

Consecutive droughts in Coimbatore dist (TN) reduced the coconut production by about 3 lakh nuts/year for 4 years. Productivity loss was to the tune of about 3500 nuts/ha/year.

Loss due to 1996 cyclone in Konaseema led to a reduction in coconut yields by about 3350 lakh nuts/year for 6 years. The loss in E. Godavari Dist was to the tune of about 2200 lakh nuts/year in 6 years. The productivity was reduced by 6200 nuts/ha/year in E. Godavari dist and by ~4100 nuts/ha/year in AP.

**Fig 3:** Coconut productivity loss due to 1996 cyclone in Godavari districts

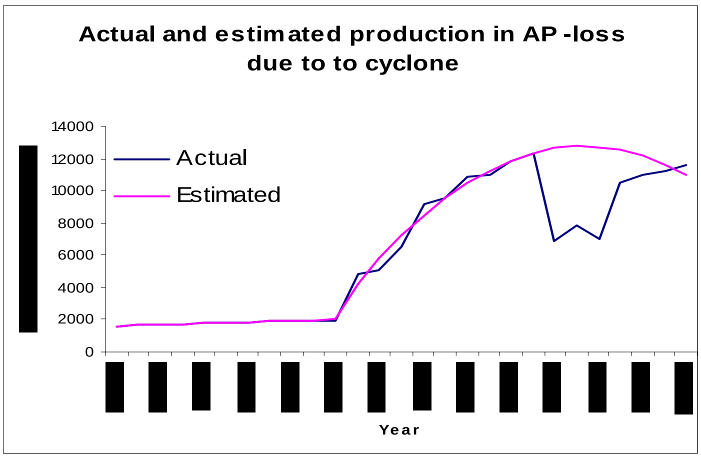


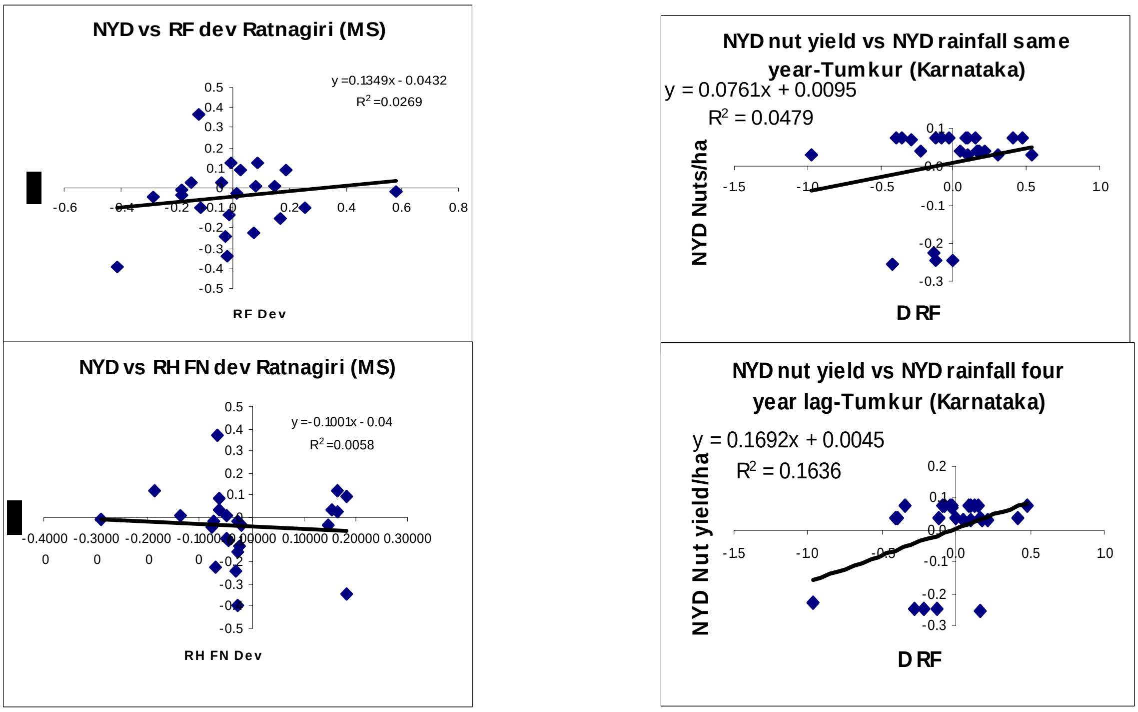
**Table 4**: Coconut production loss in AP due to 1996 cyclone

| Year | Srikakulam | E. Godavari | W. Godavari | AP state |
|---|---|---|---|---|
| 1996-97 | -28.9 | -4245.0 | -1203.7 | -5753.4 |
| 1997-98 | -456.3 | -3400.0 | -1089.2 | -4943.8 |
| 1998-99 | -604.5 | -3313.4 | -1332.0 | -5726.3 |
| 1999-00 | -706.9 | -1289.2 | 17.9 | -2019.1 |
| 2000-01 | -406.0 | -963.6 | | -1232.4 |
| 2001-02 | -71.4 | -208.0 | | -394.3 |
| Loss in 6 years lakh nuts | -2274.17 | -13419.3 | -3607.06 | -20069.5 |
| Loss lakh nuts/year | -379.0 | -2236.5 | -901.7 | -3344.9 |

**Coconut sensitivity to climatic parameters**

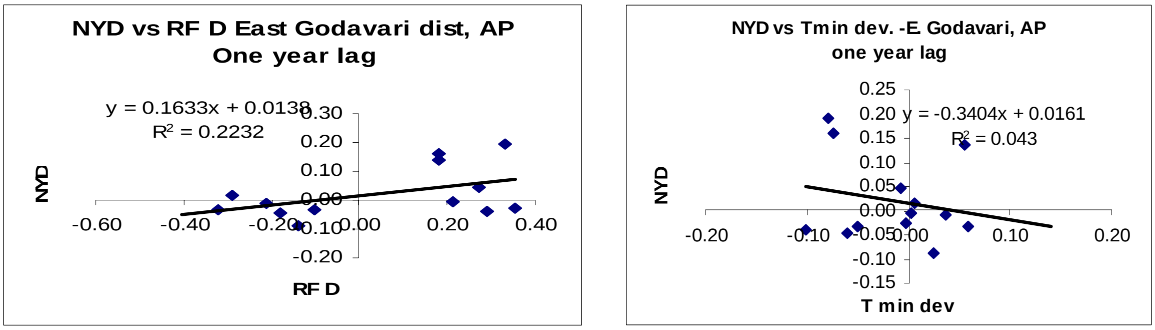
The analysis on sensitivity of coconut to weather parameters was done for locations representing different agro-climatic zones of coconut growing area. The analysis was done using one-way, two-way and three-way trend analysis. The normalized yield deviations were Z –plotted against the normalized deviations of Tmin, Tmax, T difference, RH, Sunshine duration, rainfall, etc. Since the coconut palm taked 44 months from inflorescence primordial initiation to the nut maturity, the analysis was done using current year, one-year, two-year, three-year and four-year lag periods. Some of the results are presented below

**Fig 4:** Sensitivity of coconut yield- De-trending analysis was done in 1, 2, 3, 4, year lags




The results indicate that rainfall deviation has higher impact on yield of 4 year to follow. However, the Tmax has higher impact on current and one year lag periods. A multiple regression analysis is being done to find out the overall impact of weather variables on coconut yield.

**Fig 5:** Sensitivity of coconut to climate –rainfall and T min in coastal AP




**Yield deviation projections in different scenarios of climate change**

Maidan parts of Karnataka, Eastern TN, Lower coastal AP, Upper coastal AP, Pondicherry, WB and Assam in decreasing order are found to be hot spots as per different scenarios (A2a, A2b, A2c, A1f, B2a, B2b) of climate change (HadCM3 model) for 2020, 2050 and 2080. An analysis on coconut yield deviation projections indicated negative trends in coastal MS, South-East TN, Coastal AP and WB in different scenarios (A2a, A2b, A2c, A1f, B2a, B2b) of HadCM3 model. No change in productivity was projected in coastal Karnataka and Kerala. The actual station values for the year 1980 were used as base values. No significant changes in yield are projected for pepper under different scenarios.

**Table 5:** IPCC HADCM3 Scenario based hot spots among coconut area for climate change

| Scenario | Top five hotspot areas | | | | |
|---|---|---|---|---|---|
| A2a | Karnataka (T) | E TN & Pond | LC Co AP | N WB | C Assam |
| A2b | Karnataka (T) | E TN & Pond | S TN (V) | S WB | N WB |
| A2c | Karnataka (T) | S TN | LC Co AP | U Co AP | N WB |
| B2a | Karnataka (T) | Karnataka (A & T) | Goa | E TN & Pond | U Co AP NWB |
| B2b | Karnataka (T) | S TN (V) | LC Co AP | S WB | |

**Fig 6**. Coconut yield deviation projections in HadCM3 scenarios in 2020,2050 and 2080 in different agro-climatic zones

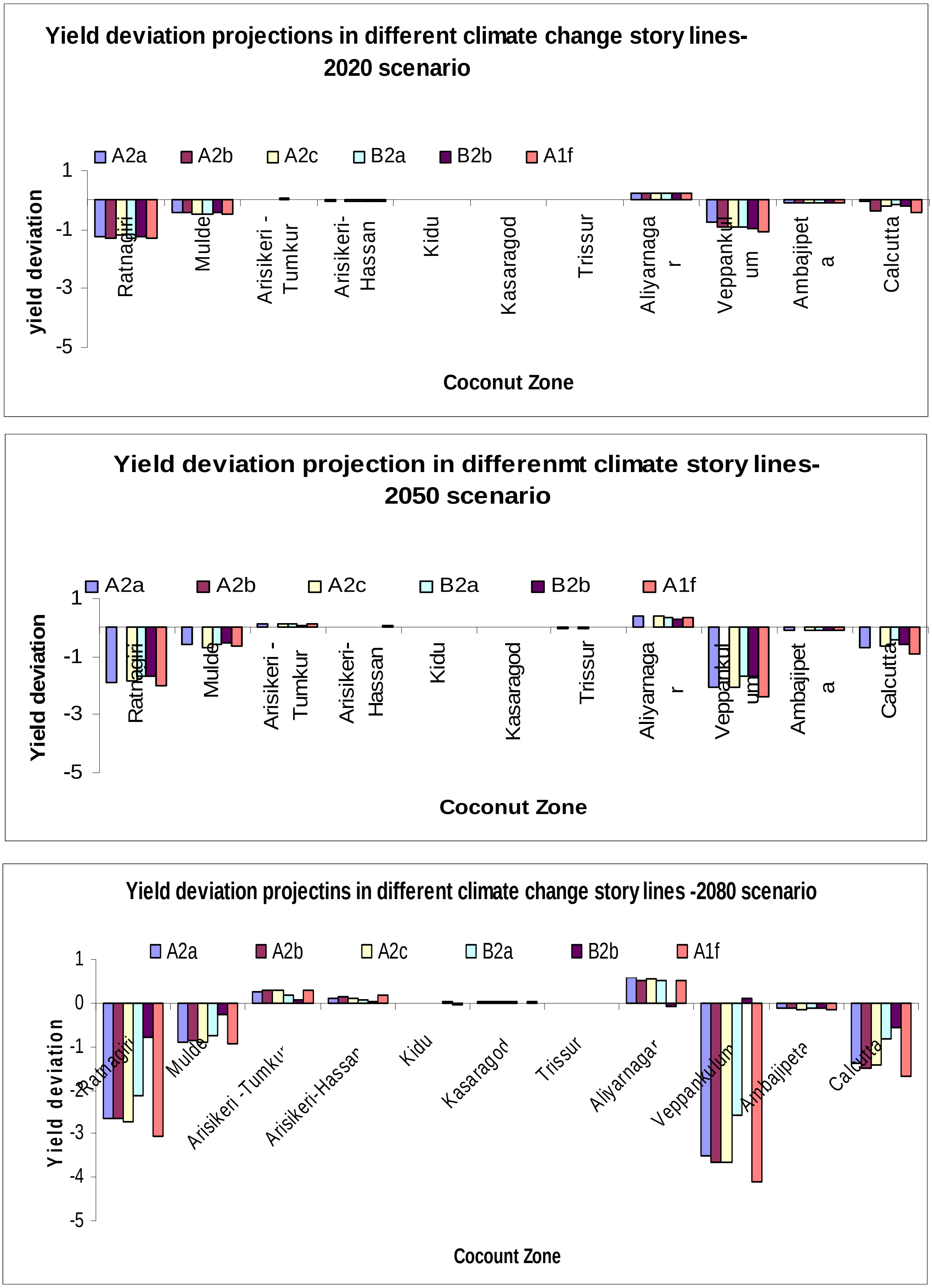


**Table 6.** Pepper yield deviation projections in HadCM3 A2a scenario in 2020,2050 and 2080 in different agro-climatic zones

| Year | Valparai | | | | Wynad | | | |
|---|---|---|---|---|---|---|---|---|
| | Rainfall (mm) | Tmax $^0C$ | Tmin $^0C$ | NYD | Rainfall (mm) | Tmax $^0C$ | Tmin $^0C$ | NYD |
| 2020 | 5181 | 25.5 | 16.6 | 0.0252 | 2605 | 31.70 | 20.82 | 0.193 |
| 2050 | 5182 | 26.4 | 17.5 | 0.0183 | 2600 | 32.63 | 21.74 | 0.222 |
| 2080 | 5184 | 27.4 | 18.5 | 0.0108 | 2592 | 33.59 | 22.68 | 0.251 |

Pepper productivity is generally higher in higher elevations such as Wynad and Idukki. Relatively cool climate of these regions may have influence on productivity. From the table given below, it is clear that the temperature (both Tmax and Tmin) of both Idukki and Wynad is about 6-7 degree lesser than that of Cannanore or Trichur.

**Table 7**. Temperature deviation and pepper yield in different agro-climatic zones

| Region | Temperature (1984-04) | | |
|---|---|---|---|
| | Mean Tmax (ºC) | Mean Tmin (ºC) | Mean yield (kg/ha) |
| Wynad | 27.3 | 17.6 (9.7) | 402 |
| Idukki | 27.5 | 15.6 (11.9) | 327 |
| Cannanore | 33.1 | 22.6 (10.5) | 241 |
| Trichur | 32.1 | 23.4 (8.7) | 239 |

**Growth response of coconut seedlings and pepper to elevated temperature and $CO_2$ levels**

- Among 3 cultivars (WCT, LCT and COD) and 2 hybrids (WCT x COD, COD x WCT), COD has shown early response to elevated $CO_2$ (500 and 700 ppm) and elevated temp. (2 $^oC$) after 3 months of exposure.
- Increase in shoot height, leaf area and soot dry matter due to elevated $CO_2$ was to the tune of 36% over chamber control
- Decrease in above parameters in elevated temp. (2 $^oC$) was to the tune of 40% over chamber control
- In pepper, the percentage variation was less than 10 for both leaf area as well as plant height after 4 months of growth at elevated temperatures (2 and 2.7 $^oC$)

Plate 2: Coconut seedlings in OTCs

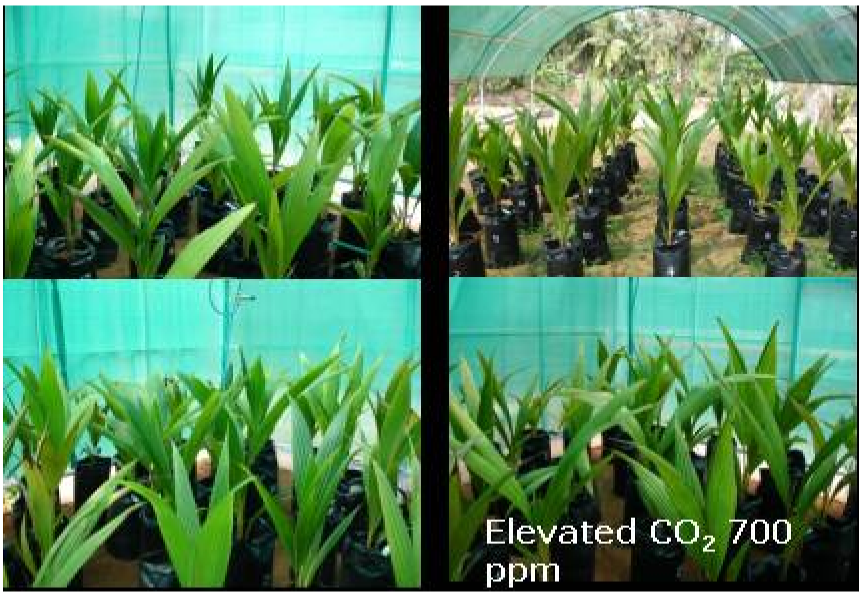
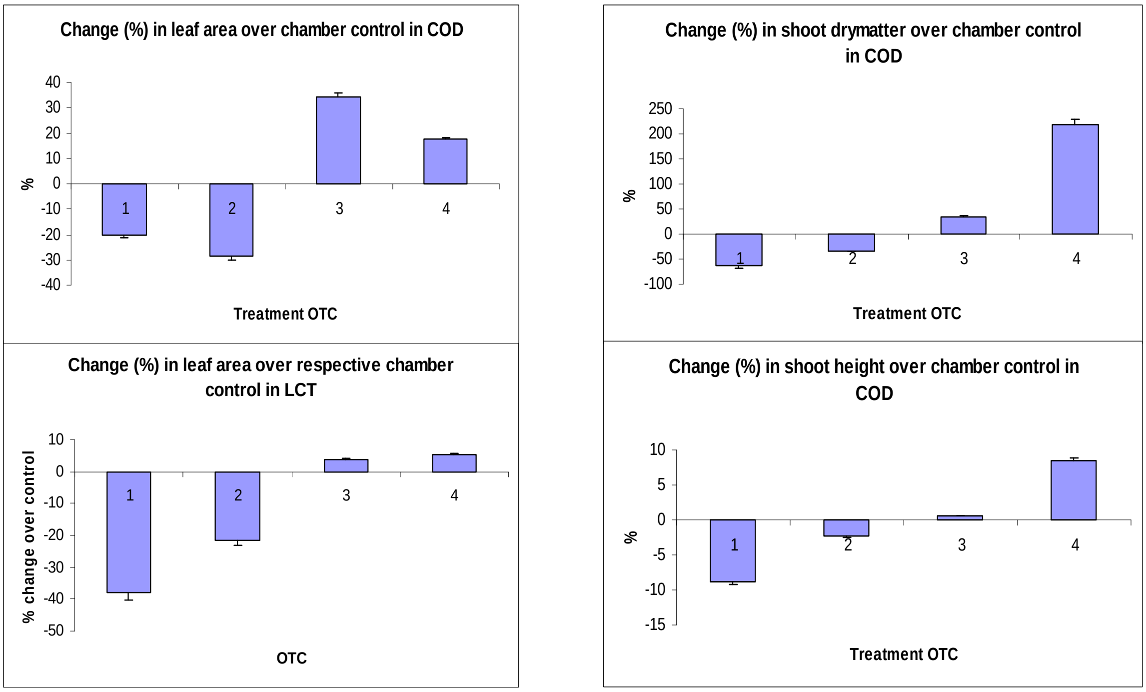


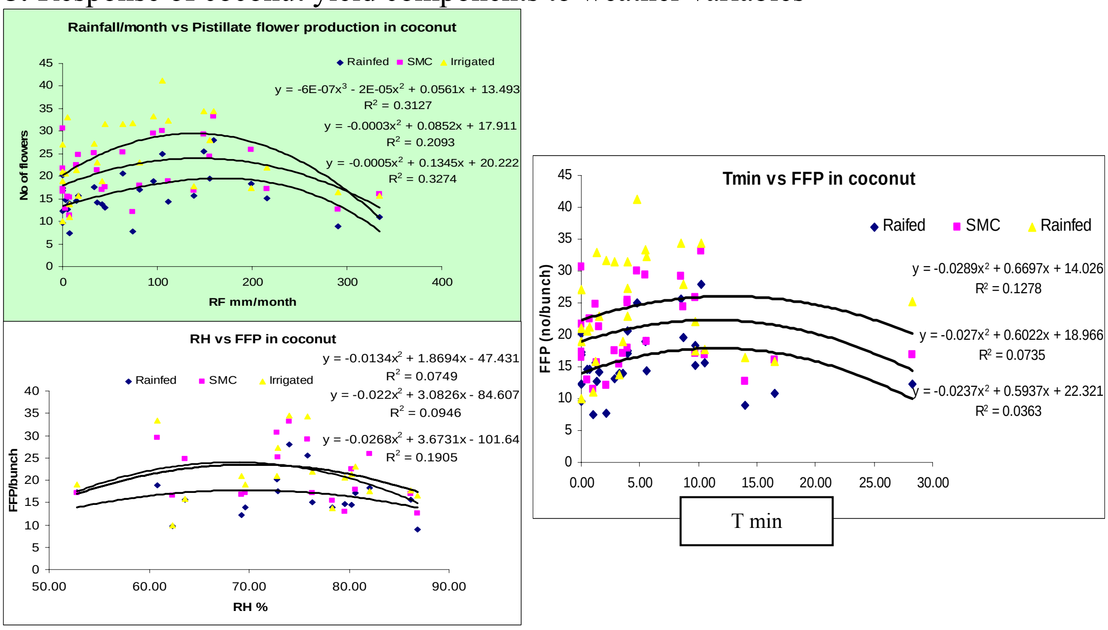
**Fig 7**: Response of coconut seedlings to elevated $CO_2$ and temperature




## Regression analysis indicated

- Increase in T min increased the leaf emergence rate
- Increase in T max increased inflorescence emergence rate
- Increase in RH increased the GDD requirement for inflorescence emergence
- Pistillate flower production has curvilinear relationship with rainfall/month 150mm/month-opt), T min (15 °C-opt) and RH (70%-opt)
- Nut retention has curvilinear relationship with T max (32 °C-opt) and T min (20 °C-opt)
- coconut yields increase up to 44 °C of Tmax and then decline

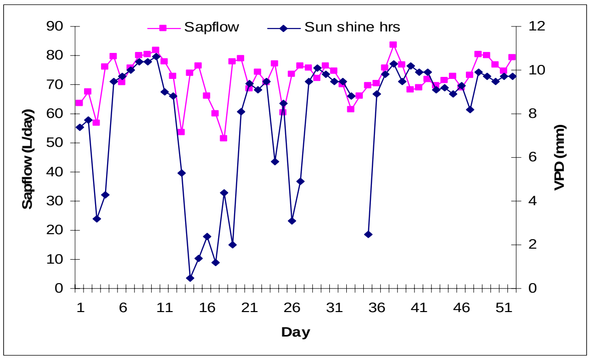
**Fig 8:** Response of coconut yield components to weather variables



### *Sapflow analysis in coconut*

For the first time in world, the sap flow studies in coconut are done. The coconut sap flow varied from 30 to 70 L/day depending on the palm type and atmospheric conditions. Initial estimates indicated that for the development of one nut approximately 40 to 50 L of sap flow takes place. Sapflow is highly influenced by VPD and other weather variables.

**Fig 9**: Response of sapflow in adult coconut palms to weather



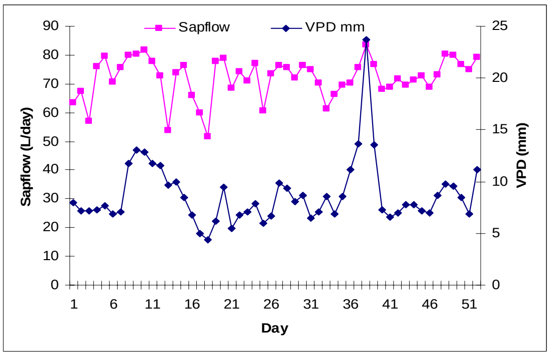



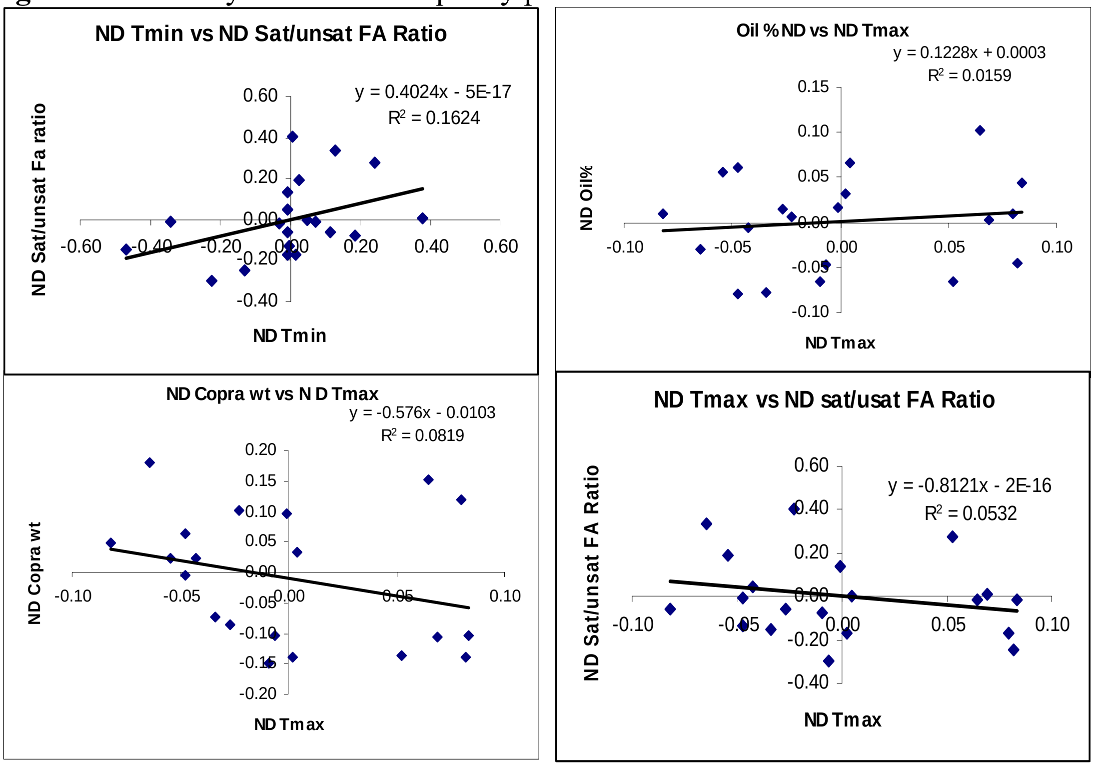

**Table 8**: Pepper plant height and leaf area as affected by elevated temperature (2.7 $^{o}$C)

| Variety | Initial | | After 1 month | | After 2 months | | After 4 months | |
|---|---|---|---|---|---|---|---|---|
| | Pl.ht. (cm) | Leaf area (cm$^2$) | Pl.ht. (cm) | Leaf area (cm$^2$) | Pl.ht. (cm) | Leaf Area (cm$^2$) | Pl.ht. (cm) | Leaf area (cm$^2$) |
| P1 | 7.4 | 81.601 | 13.2 | 140.669 | 17.7 | 170.068 | 24.0 | 227.29 |
| P3 | 6.9 | 70.301 | 13.8 | 147.999 | 19.8 | 211.80 | 31.9 | 243.892 |
| P4 | 6.5 | 95.036 | 12.7 | 132.187 | 20.0 | 184.83 | 22.9 | 212.828 |
| P5 | 9.8 | 86.008 | 16.7 | 154.479 | 21.8 | 189.405 | 34.6 | 237.563 |
| P6 | 7.7 | 78.598 | 15.2 | 88.386 | 22.2 | 139.872 | 30.2 | 96.776 |
| P7 | 7.9 | 73.626 | 12.9 | 141.152 | 18.9 | 193.217 | 26.7 | 242.261 |
| P24 | 7.7 | 68.410 | 15.3 | 118.948 | 20.6 | 157.135 | 32.8 | 131.987 |
| HP 105 | 9.2 | 64.354 | 11.4 | 85.501 | 17.7 | 124.042 | 21.8 | 150.702 |
| Sreekara | 11.1 | 60.174 | 18.5 | 87.807 | 24.4 | 128.222 | 27.3 | 78.667 |
| Subakara | 8.4 | 53.488 | 14.6 | 81.311 | 20.9 | 115.746 | 24.3 | 64.590 |
| Mean | 8.3 | 73.2 | 14.4 | 117.8 | 20.4 | 161.4 | 27.7 | 168.7 |

**Quality of coconut and pepper in relation to Climate change scenarios**

The copra yield/nut, oil percentage and fatty acid profiles of various cultivars grown at different agro-climatic zones was analyzed for their relationship with the weather during nut growth periods for the nuts harvested during January, April, July and October months. The normalized deviations of these parameters were Z plotted against the normalized deviations of weather parameters during the copra development period.

**Fig 10**: Trend analysis of coconut quality parameters and weather.




The analysis indicated impact of Tmax, Tmin, Rainfall, RH on the copra yield/nut, oil % and fatty acid composition in coconut oil. The normalized deviations did not show any significance among HadCM3 scenarios and current trends.

Copra drying temperatures did not influence the fatty acid profile in coconut oil except of some long chain fatty acids which are in very low conc. Variation in MCFAs in WCT grown at different agro-climatic zones was found maximum in nuts harvested during Jan, Oct and Jul and least in those harvested in April. Among the agro-climatic zones, the seasonal variation for LCSFAs was maximum in Ambajipeta and min. at Kasaragod and Ratnagiri.

In pepper, samples from higher elevation (Wynad and Idukki) showed slightly lower oil and piperine content. Sabinine+myrcine was noticed in samples from higher elevation but occasionally noticed in samples from lower elevation

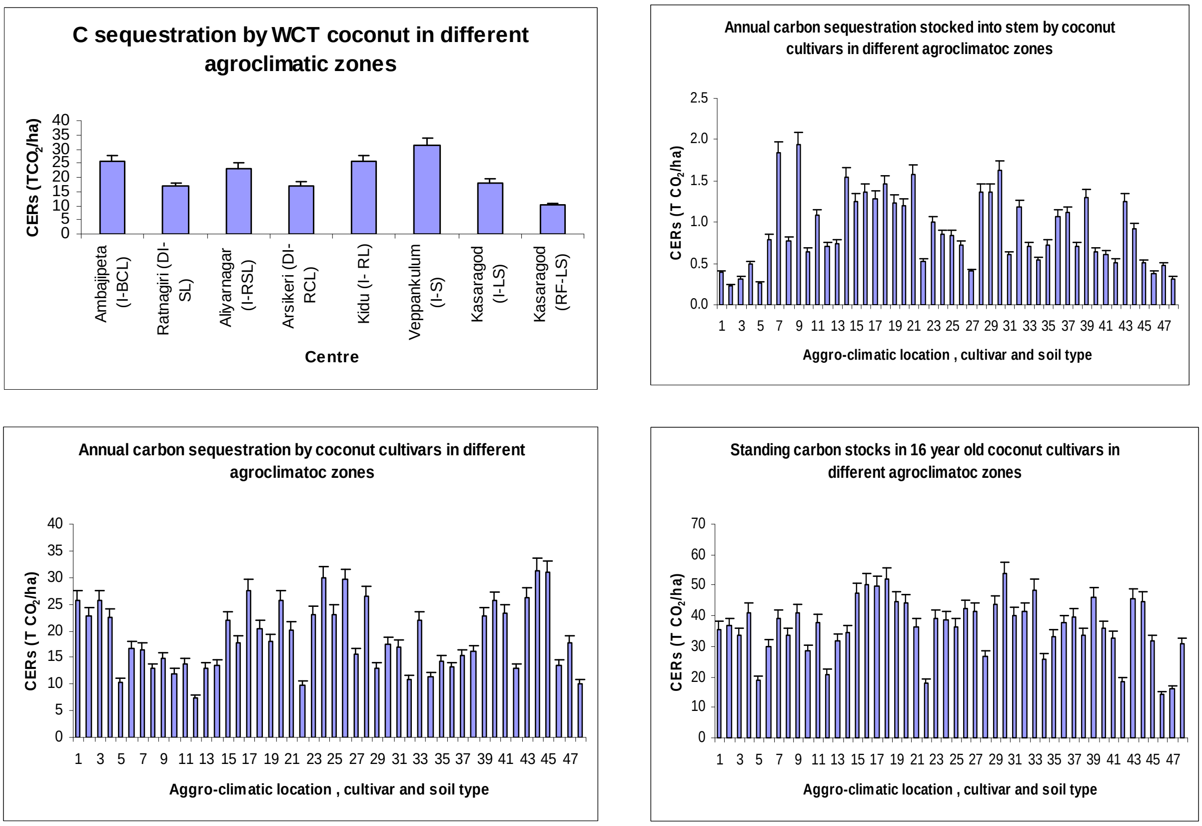
**Carbon sequestration and carbon stocks in coconut**

In order to study the carbon sequestration and carbon stocks in coconut plantations under different agro-climatic zones, about 470 palms of Tall, Dwarf and Hybrids were tagged and the data on various parameters were taken. For estimating the carbon stocks in coconut, a method for non-destructive estimation is developed and is being tested. Using this simple equation, it is possible to estimate the stem dry weight. The formula is based on height of the stem. Girth of the stem and both are multiplied by a factor. Using this formula and other already available formulae to estimate annual dry matter production, it is now possible to estimate the whole plant carbon stocks and sequestrations which will be analyzed and worked-out. Apart from this variations due to cultivar, agro-climatic zone and management is to be analyzed

- Annual C sequestration in coconut above ground biomass varied from 15 CERs to 35 CERs depending on cultivar, agro-climatic zone, soil type and management.
- Annually sequestered carbon stocked in to stem in the range of 0. 3 to 2.3 CERs
- Standing C stocks in 16 year old coconut cultivars in different agro-climatic zones varied from 15 CERS to 60 CERs

- Annual C sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils
- The carbon content in different tissues of coconut was analyzed and estimates for carbon sequestration by coconut are given below.

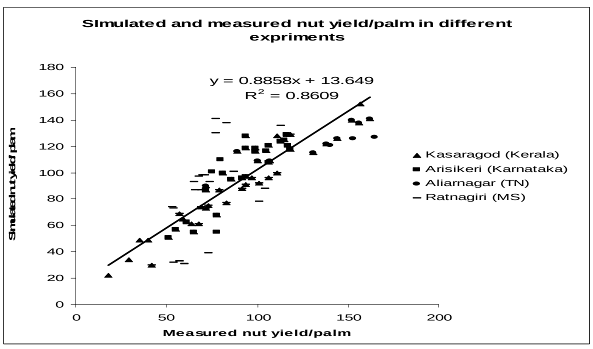
**Fig 11**: Coconut carbon sequestration and carbon stock potential in different agro-climatic zones and cultivars




## Coconut simulation model for impact assessment of climate change

For the first time, a coconut simulation proto-model is developed based on various phenological, physiological and crop environmental parameters. This will be further calibrated, validated and verified for use in projecting the coconut growth and yield in changing climatic scenarios of 2020, 2050 and 2080. The model can run for entire coconut growth period and gives output for monthly yields apart from other parameters.

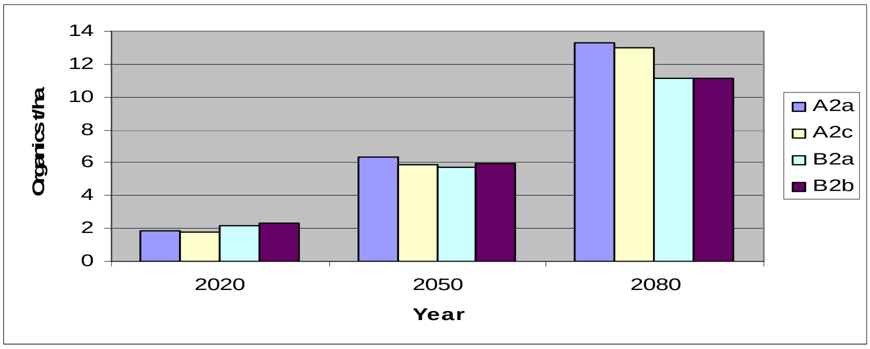
**Fig 12**: Validation results of coconut simulation model -nut yield



**Soil carbon storage and mitigation strategies for maintenance of soil organic carbon**

- Soil organic carbon range - 0.041 to 0.652 %
- Ratnagiri soils had higher coefficient of variation
- Arsikere soils soil C store was in the range of 2.248 -2.997 kg/m$^2$. The average soil C store in the Ambajipeta soils ranged from 0.462 – 1.604 kg/m$^2$.
- The soil C store values of the Aliyarnagar CRS soils revealed that in the NPK experimental plot, basins of the coconut which did not receive any fertilizer had more stored soil C than that of other treatments.
- Simulation studies revealed that the equilibrium SOC would be 98.5 % of the base level for 5˚ C temperature rise.
- The estimated additional organic manure requirement for different climate scenarios ranged from 9.3 to 13.3 t/ha/year during 2080 for equilibrium with current levels

**Fig 13**: Estimated requirement of organic matter for different CC scenarios




**Socio-economic impacts and adaptation of farmers to impact of climate change on plantation crops**

Field survey is conducted in two drought prone districts to asses the impact and adaptation Coimbatore district in Tamil Nadu (Pollachi Taluk) and Tumkur district in Karnataka (Madhugiri & Pavagada Taluks) for coconut and Wayanad (Kerala) for pepper to assess the impact of drought in plantation crops.

To assess the impact of drought on socio-economic aspects of coconut farmers in district a field survey was conducted during 2005-07 in about 200 coconut gardens located at random through cluster sampling. Coconut palms were affected severely to moderately in many parts of Coimbatore and Tumkur districts, creating huge financial loss to farmers and the States Agricultural Economy. More than 2 lakh palms were dead and about 6 lakh coconut palms were severely/partially affected due to drought in Coimbatore and Tumkur Districts Farmers who adopted SMC or Drip irrigation could reduce the drought impact on their plantations. The economic loss is to the tune of Rs.2 lakhs / ha. Though moisture conservation measures were followed, consecutive drought years aggravated the economic loss. Pepper vines were affected moderately to severely in parts of Wayand district of Kerala State, creating financial loss to farmers and the State’s Agricultural Economy. The economic loss is to the tune of Rs.0.35 lakhs / ha. Compensations were given @ Rs 50/partially affected palm (2-3 leaves existing) and Rs 150/fully affected (dead) palm.

The drought situations in Coimbatore (TN) and Wayanad (Kerala) districts led to change in cropping pattern. For instance, in Coimbatore and Tumkur dists, the dried coconut plantations were cut and the land is either changed to cultivate the annual crops like green gram, maize and other pulses or oil seeds; or are converted to plots for non-agricultural use. The cropping pattern changed during past 50 to 60 years in these areas. The reasons attributed to were shortage of labour force, market demand, low rainfall, high temperature and water scarcity.

**Table 11**: Impact of drought on adopted (drought management) and non adopted farmers

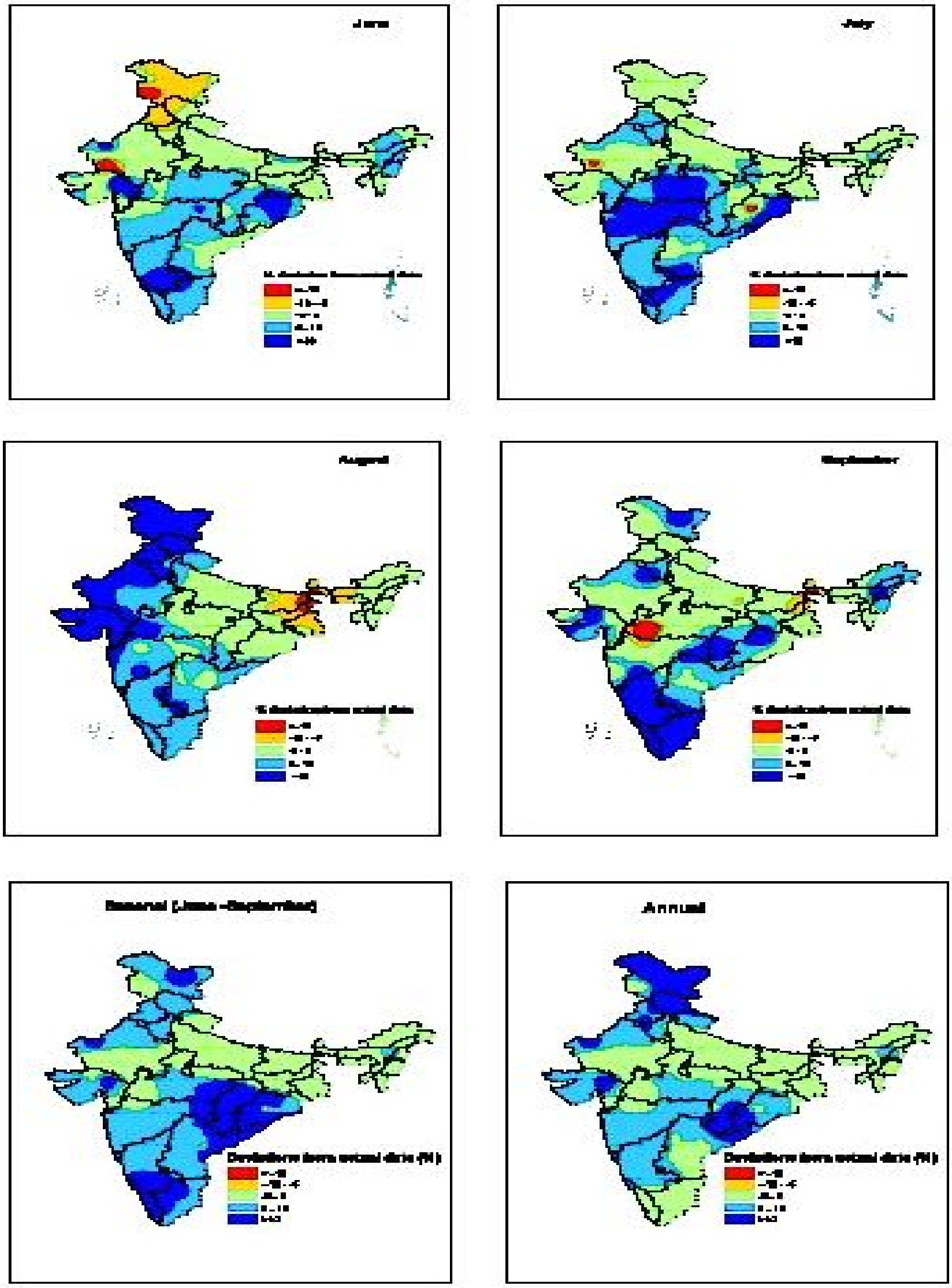
| Type | No. of farmers | (%) of farmers | (%) of palms affected |
|---|---|---|---|
| **Adopted** | 56 | 56.6 | 38 |
| **Non-adopted** | 43 | 43.4 | 44 |

## Central Research Institute for Dryland Agriculture

**Analysis of climate data for climate change**

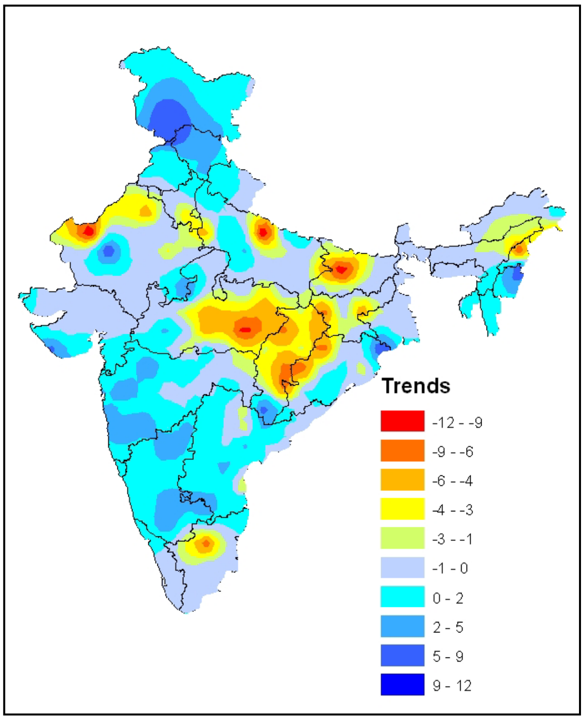
The daily rainfall output for the year 2005 of PRECIS model converted into monthly, seasonal and annual rainfall obtained at various rain gauge stations located in different grid points, which was derived from the projected values of 2020 and comparing it with the actual values has been carried out. The percent deviations between the actual and predicted have been computed for each station. The spatial maps for the individual months as well as for *kharif* season and for the whole year have been prepared and shown below.

Evaluation of Model Projections with observed mean rainfall data (1990-2005)



In general, the area under positive deviations is higher compared to normal and negative deviations. This shows the model output overestimated the rainfall at many locations. The deviations are near normal across Indo-Gangetic Plains for all the months as well as for the seasonal rainfall. The overestimated pattern is mostly confined to central and the southern Peninsula part and parts of northwest India. There are no areas where the negative deviations are observed in respect of seasonal and annual rainfall departure maps.

**Rainfall trends and their significance**
From the long-term series of annual rainfall data recorded at 1140 rain gauge stations across the country, signals of rainfall trends were computed and maps have been prepared to identify the regions vulnerable to climate change, which was reported earlier. The statistical significance of these trends has been tested using Mann Kendall test for each station and spatial distribution maps showing the significant changes in annual rainfall has been prepared and presented below.




From the above figure, significant negative trends were observed in the eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, U.P., parts of northwest and northeast India and a small patch in Tamil Nadu. Significant increasing rainfall trends have also been noticed in Jammu & Kashmir and in some parts of southern Peninsula.

**Impact of climate change on Agriculture**

**1.0 Water requirements of the crops:**
The impact of climate change scenarios on the crop water requirement, crop duration at few selected locations in A.P. have been attempted and presented in the following tables. It is noticed that overall water requirements of the major crops grown under rainfed conditions in Andhra Pradesh have shown an increasing trend. This is mainly attributed to the increasing in average temperature by approximately 1 °C over the base year.

**Table.1**: Projected Crop Water Requirements

| Station | Crop | Increase in water requirements (2020-2005) mm |
|---|---|---|
| Anakapalle | Maize | 51.7 |
| | Groundnut | 61.3 |
| Anantapur | Groundnut | 70.1 |
| | Red gram | 174.3 |
| Jagityal | Cotton | 60.5 |
| | Maize | 49.0 |
| Rajendranagar | Red gram | 114.5 |
| | Groundnut | 73.0 |
| Tirupathi | Groundnut | 73.0 |

**Crop duration**

There is not much significant decrease in the crop duration due to fulfilling of the required growing degree-days at an early date. The crop duration is expected to decrease by 1 to 2 weeks by 2020 in all the major crops of the State (Table.2).

**Table.2:** Changes in crop duration

| Station | Crop | Reduction in crop duration (weeks) |
|---|---|---|
| Anakapalli | Maize | 1 |
| | Groundnut | 1 |
| Anantapur | Groundnut | 1 |
| | Red gram | 1 |
| Jagtial | Cotton | 2 |
| | Maize | 1 |
| Rajendranagar | Red gram | 2 |
| | Sorghum | 1 |
| Tirupathi | Groundnut | 1 |

**Info-Crop Castor Model**

A dynamical crop simulation model, viz., INFOCROP for castor was developed in collaboration with Department of Environmental Sciences, IARI using the data generated through field experiments conducted at CRIDA. The model has been validated with the experimental data recorded during the year 2000 for simulating the yields and the phenology of the crop. The experimental data recorded during the year 2000 for simulating the yields and the phenology of the crop. The validated results in respect of few castor-growing areas in the country are given in the following table.

**Table.3:** Validation of INFOCROP-Castor model

| Location | Yield (kg/ha) | | Anthesis (days) | | Days to maturity | |
|---|---|---|---|---|---|---|
| | Sim | Obs | Sim | Obs | Sim | Obs |
| Hyderabad | 1705 | 1458 | 57 | 42 | 157 | 150 |
| Bijapur | 1870 | 1234 | 55 | 54 | 145 | 150 |
| Kanpur | 922 | 1317 | 65 | 75 | 116 | 120 |
| Junagadh | 179 | 177 | 64 | 52 | 104 | 120 |
| Kovilpatti | 1085 | 911 | 57 | 55 | 152 | 150 |

The difference between the simulated and observed yields in respect of Junagadh and Kovilpatti are small compared to other stations' data. There is a little difference between the predicted and observed in respect of days of maturity at all the stations.

## 2.0 Impact of Elevated $CO_2$ on growth and yield of castor

The following activities were undertaken during the reporting period (2006-07)

1. To study the growth and yield of castor under elevated $CO_2$ and moisture stress
2. To study the response of castor to enhanced $CO_2$ levels at second generation

## 2.1 Experiments under taken and methodology

The seeds of castor bean (*Ricinus communis* L.) cv DCS-9 of two generations (1st generation: fresh seed; 2nd generation: the last year derived seed from the same chambers with different levels of $CO_2$ was sown in open top chambers (OTCs) of 3m x 3m x 3m diameter lined with transparent PVC sheet. The seeds were sown directly in the soil (Alfisol) to study the effect of elevated $CO_2$ levels (550ppm and 700ppm) on growth and yield of castor. Two OTCs were maintained at 700 ppm, two OTCs were with 550 ppm, two OTCs 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 length, root length, leaf area and total biomass were recorded at 10, 20, 30, 45, 60, 75, 90 and 105 DAS intervals. For each treatment three plants were sampled in two replications from each chamber. Dry weights were recorded after keeping the plant parts at 80$^{o}$C for 48 hours in hot air oven. Total biomass (g/plant), root shoot ratio, were derived from basic data. Primary yield measurements were made after harvesting the plants at 105 DAS. Number of capsules, spike length (cm/plant), spike dry weight (g/plant), capsule dry weight (g/plant), seed weight (g/plant) and 100 seed weight were recorded. Total oil content was determined by using soxhleter.

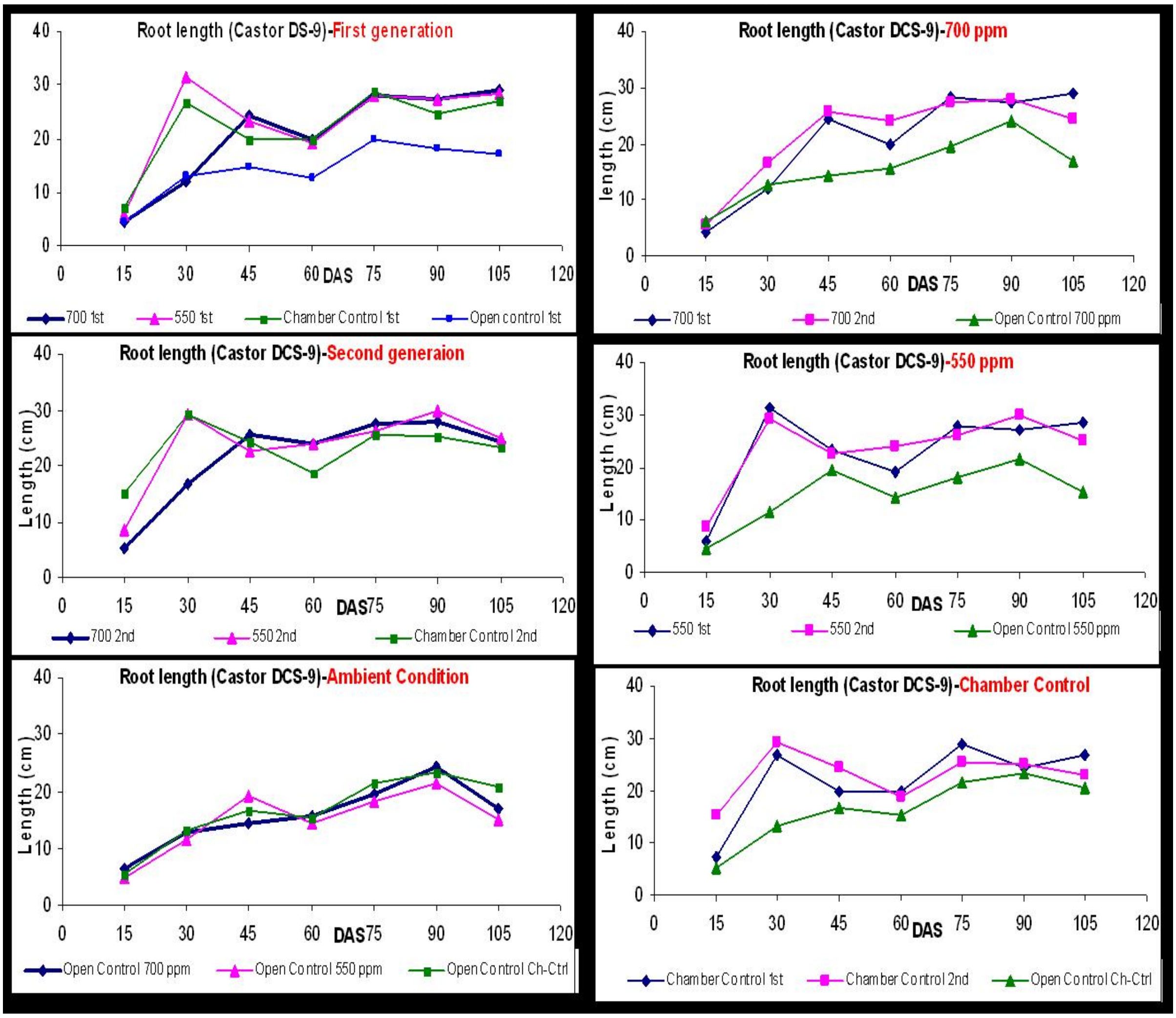
## 2.2 Results

Two generations castor crop showed significant response under elevated $CO_2$ levels (700 & 550 ppm) in terms of growth, biomass and yield. The growth characters *viz*., root and shoot lengths, root shoot ratios, leaf area, root, stem, and leaf dry weights and specific leaf area were fund to be significant at 550 and 700ppm $CO_2$ in both the generations.

### 2.2.1 Root length

Root length increased throughout the crop growth period i.e., from 10 to 105 DAS. Highest root length was recorded at 105 DAS in all the treatments. The root length under elevated $CO_2$ was higher at all stages when compared to Ch-control (Fig. 1). Among the elevated $CO_2$ levels 700ppm showed better response than 550ppm. During the crop growth period at 700ppm the first generation crop showed higher root lengths than 500ppm and chamber control, the second-generation 700ppm crop showed higher root lengths under 700ppm than 700ppm crop grown under open control. The percent increase on 105 DAS at 700ppm over 500ppm (4%), chamber control (7.6%) and open control (72.6%) in first generation, -1.5% over 550ppm, 5.1% over chamber control and 26.5% over open control in second-generation crop.

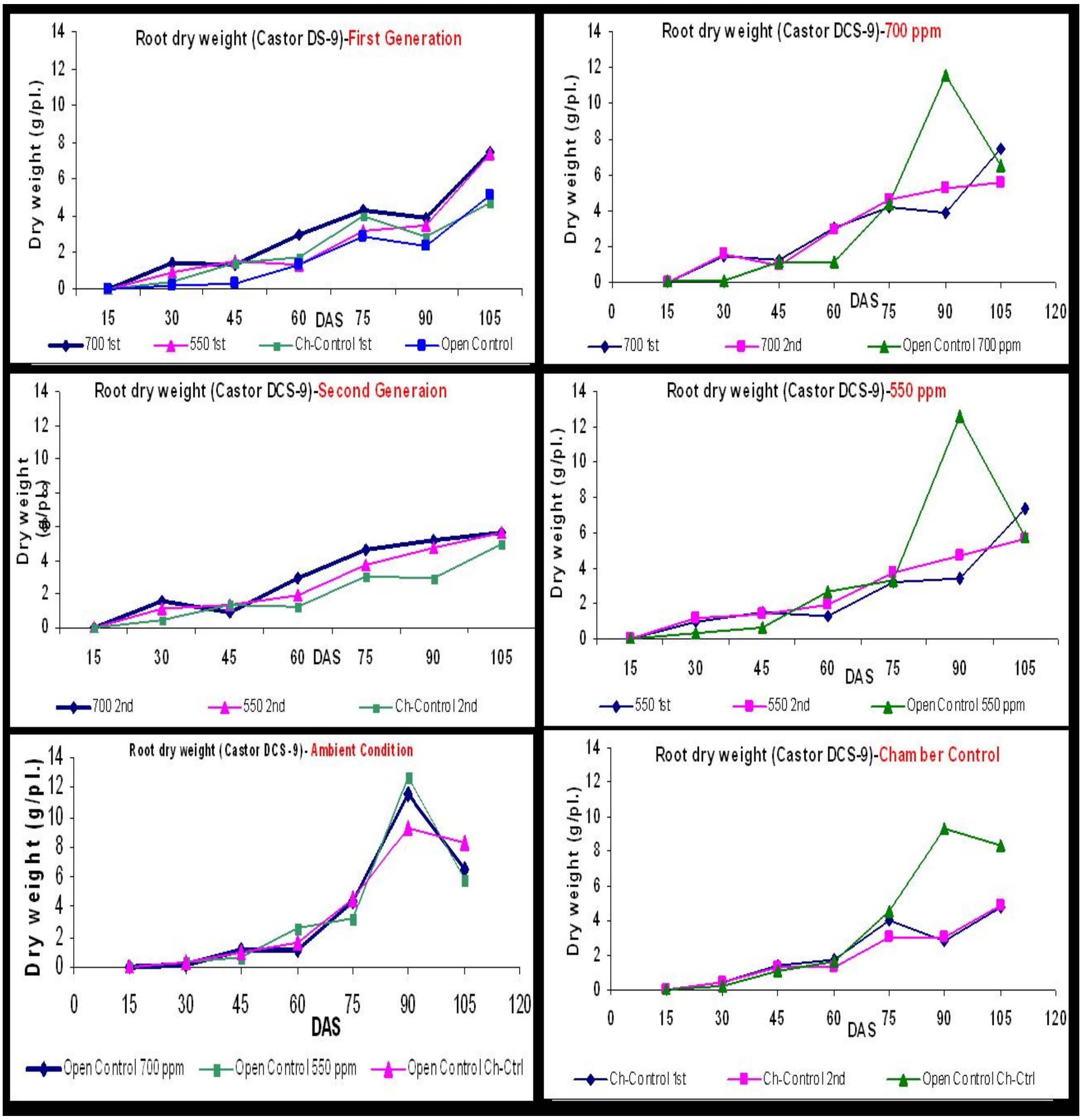
**Fig-1: Root length of castor under different levels of elevated CO2 (700, 550ppm) over chamber control and open control**



### 2.2.2 Root dry weight

Root dry weight followed the same trend as that of the root length. It increased from 10 to 105 DAS. Initially root dry weight increased slowly and from 60 to 90 DAS it showed maximum increase (Fig. 2) in both generations. The highest root dry weight was recorded at 105 DAS in all the treatments in first generation. The root dry weight percent increase on 105 DAS at 700ppm over 550ppm was 4.8%, chamber control 72%, open control 59% in first generation, and in second generation it was 1.9% over 550ppm, 15% over chamber control, -28% over open control.

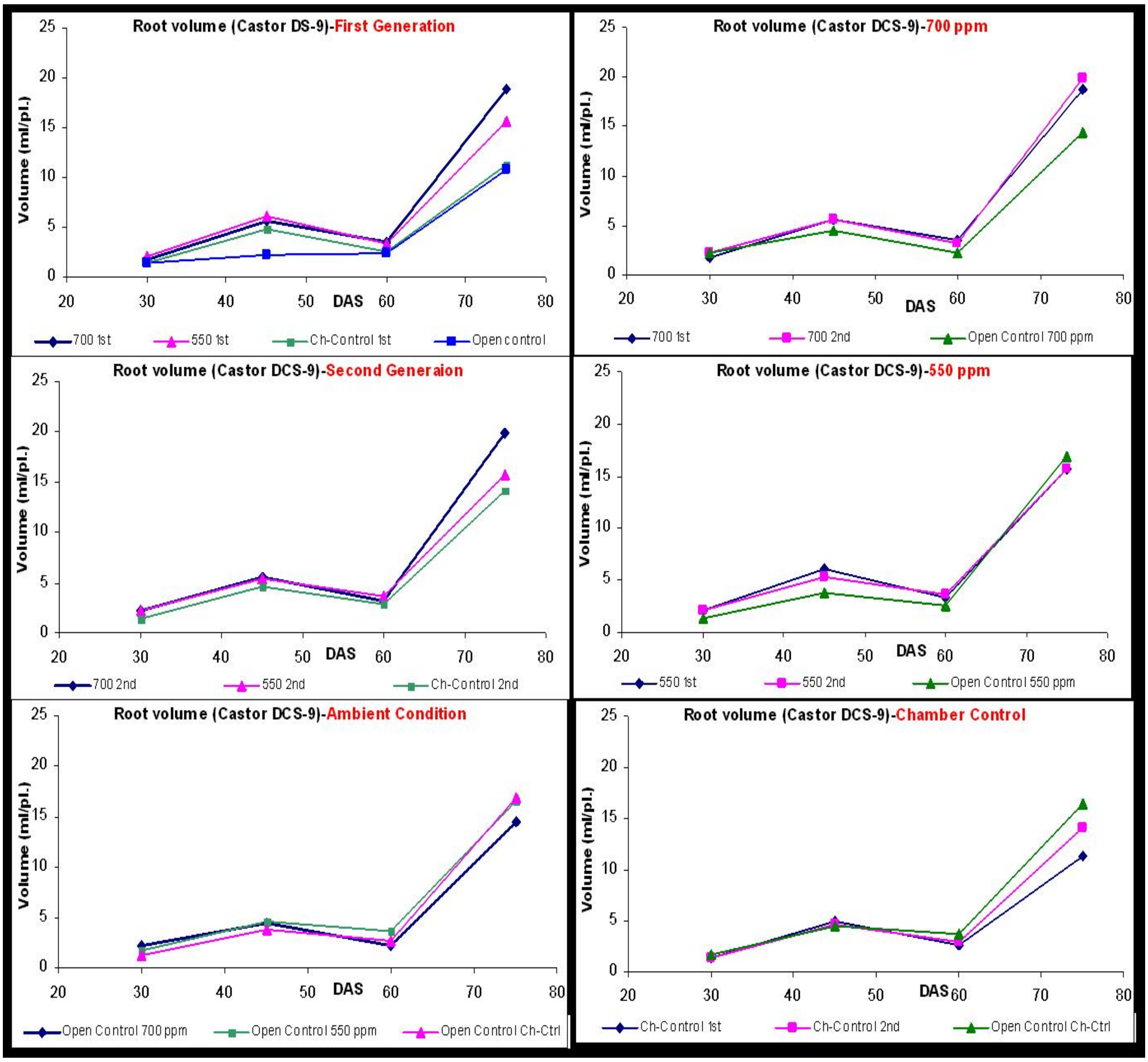
**Fig-2: Root dry weight of castor under different levels of elevated CO2 (700, 550ppm) over chamber control and open control**



### 2.2.3 Root Volume

Root volume was recorded from 45 to 75 DAS, Root volume followed the same trend as that of root dry weight and root length. It showed maximum increase on 75 DAS in all the treatments in both generations at 700ppm. The increment in root volume was more when compared to increment in root length under 700ppm of second generation under same concentration compare to Ch- control. (Fig.3). The root volume was increased at 700 ppm on 105 DAS (28%) over 500ppm, (129%) than chamber control, (70%) than open control in first generation and in second generation it was 39% over 550ppm, 90% over chamber control and 84% over open control.

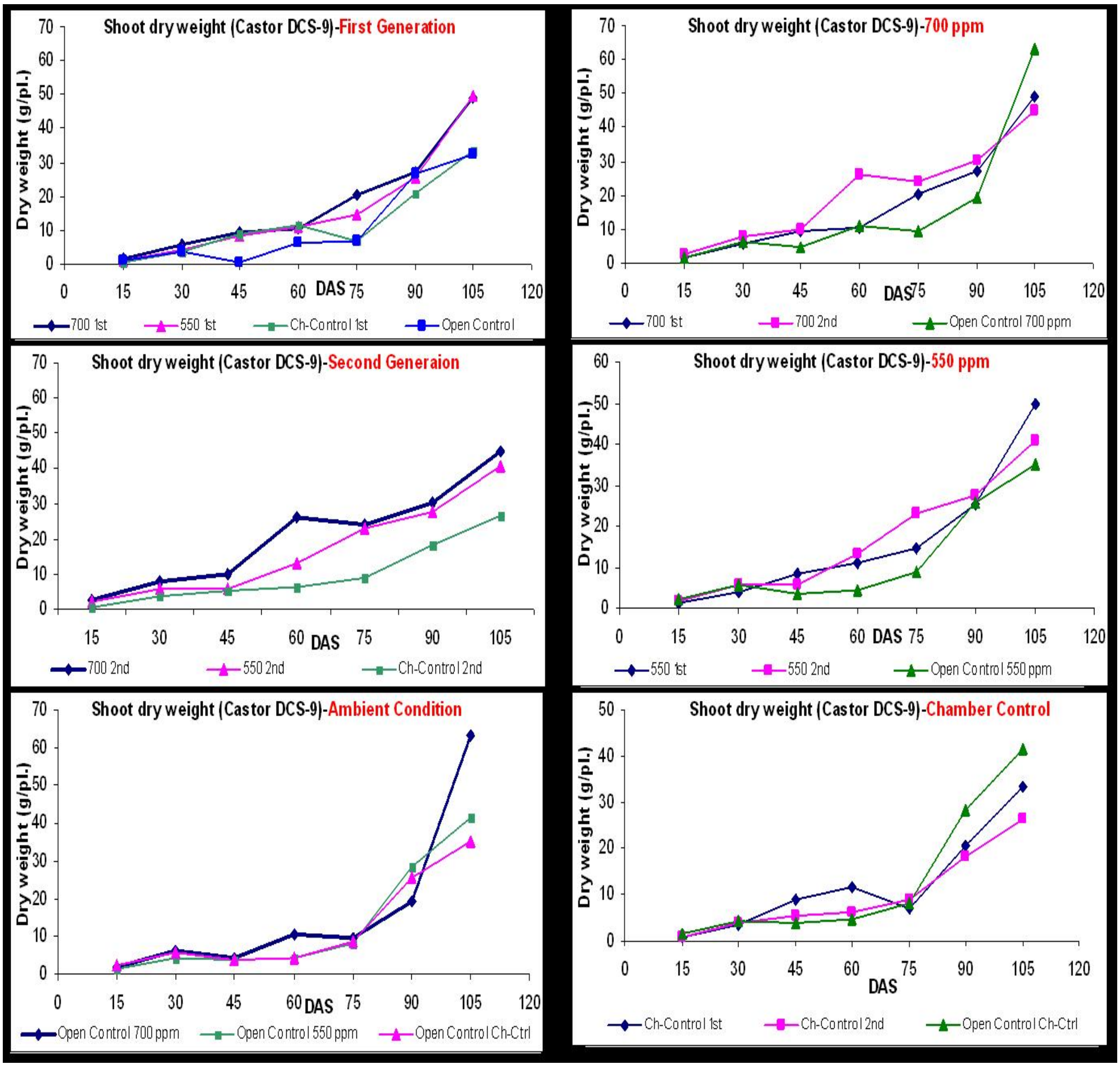
**Fig-3: Root volume of castor under different levels of elevated CO2 (700, 550ppm) over chamber control and open control**



## 2.2.4 Shoot length

Shoot length also increased from 10 to 105 DAS in all the treatments. Under 700ppm in first generation and 550ppm in second generation, shoot length was higher Ch-control at all stages of crop growth (Fig-4). The percent increase at 700ppm over 500ppm (6.1%), chamber control (29.6%) and open control (30%)in first generation, 3.4 % over 550ppm, 26.7% over chamber control and 11.5% over open control in second generation crop was observed.

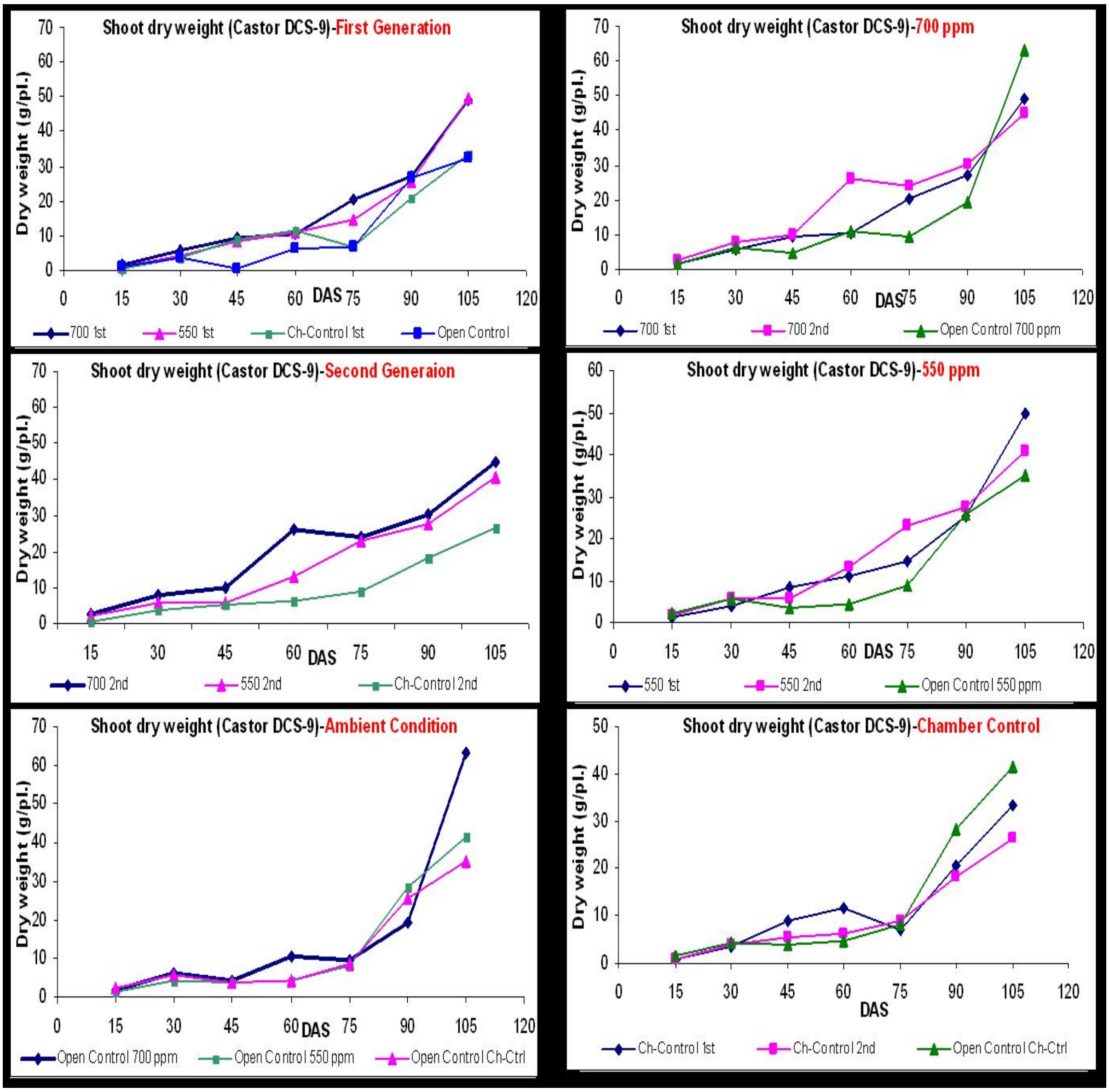
**Fig-4: Shoot length of castor under different levels of elevated CO2 (700, 550ppm) over chamber control and open control**



### 2.2.5 Stem dry weight

Stem dry weight increased throughout the crop growth period under elevated $CO_2$. Elevated $CO_2$ significantly enhanced the stem dry weight (Fig-5). Initially the increase in stem dry weight was low and from 45 DAS onwards the increment was found high in all the treatments in both generations under elevated $CO_2$. The shoot dry weight was increased at 700 ppm on 105 DAS (4.3%) over 500ppm, (69%) than chamber control, (54%) than open control in first generation and in second generation it was 10% over 550ppm, 81% over chamber control and -26% over open control.

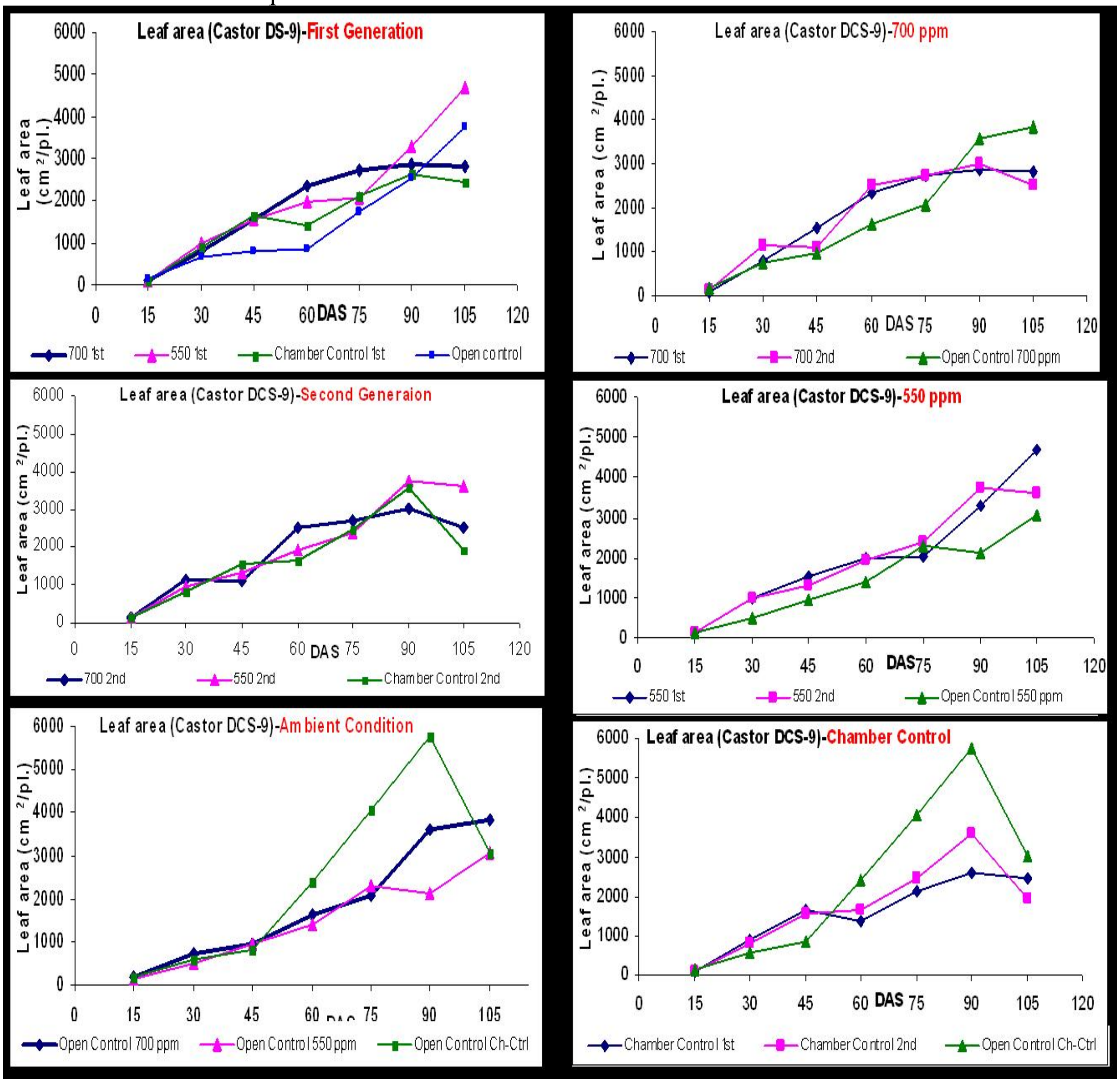
**Fig-5: Shoot dry weight of castor under different levels of elevated CO2 (700, 550ppm) over chamber control and open control**



### 2.2.6 Leaf Area

Leaf area increased from 10 to 105 DAS in all the treatments. Under elevated $CO_2$, 700 ppm showed maximum leaf area compared to 550 ppm and Ch-control (Fig-6) in two generations. The percent increase on 105 DAS at 700ppm over 500ppm (-33%), chamber control (19%) and open control (0.6%)in first generation, -30 % over 550ppm, 29% over chamber control and -33% over open control in second-generation crop.

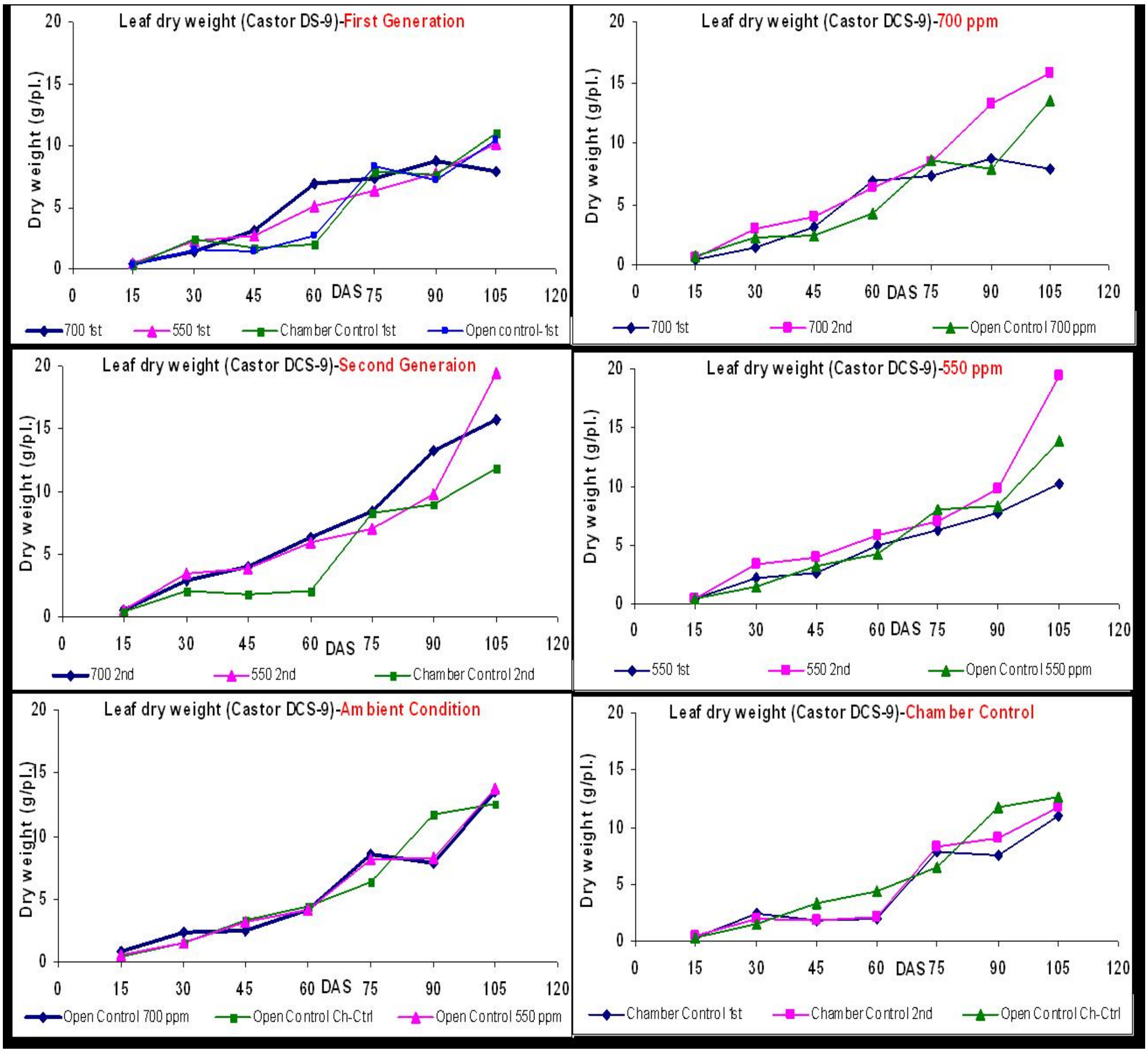
**Fig-6**: Leaf area of castor under different levels of elevated CO2 (700, 550ppm) over chamber control and open control



### 2.2.7 Leaf Dry Weight

Leaf dry weight increased throughout the crop growth period from 10 to 105 DAS. Initially the leaf dry weight was low and from 45 DAS, it showed maximum response. The leaf dry weight was high under 700ppm followed by 550ppm than Ch-control (Fig.7) in both generation. On 105 DAS the leaf dry weight was decreased under 700ppm due to more senescence and it was -14% over 550, -25% over chamber control and –44% over open control in first generation and in second generation it was –17% over 550ppm, -25% over chamber control and –3% over open control.

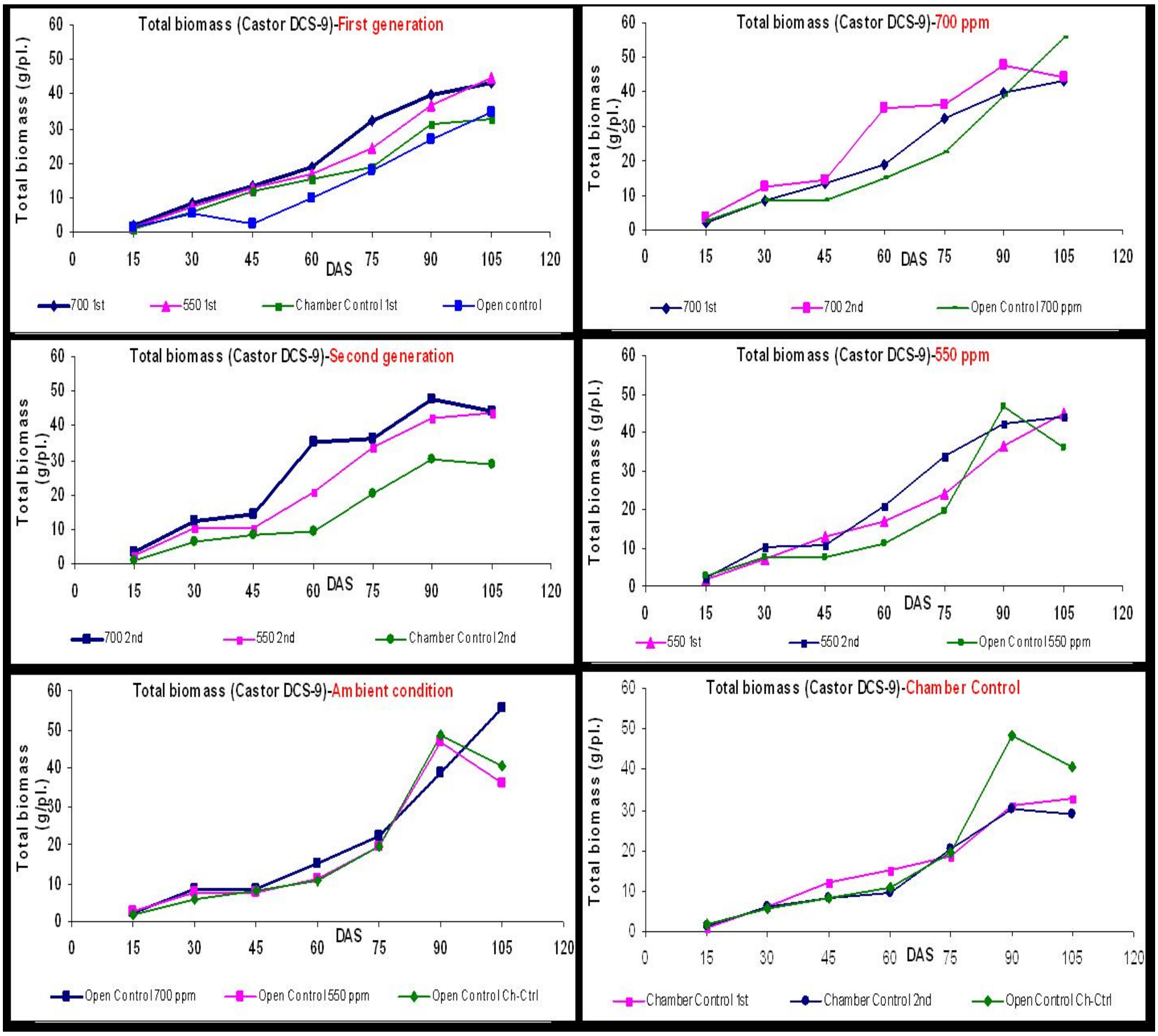
**Fig-7: Leaf dry weight of castor under different levels of elevated CO2 (700, 550ppm) over chamber control and open control**



### 2.2.8 Total Biomass

Elevated $CO_2$ levels enhanced the total biomass at all growth stages in both generations. Total biomass was maximum under 700ppm followed by 550ppm and Ch-control. Initially up to 45 DAS, there is a gradual increase in total biomass whereas an exponential increase in total biomass was observed from 60 DAS onwards. The percent increment in total biomass at 700ppm on 105 DAS, 0.2% than 550 ppm 47% than Chamber control in first generation. The highest response was recorded 59% over 550ppm in second generation (Fig.8).

**Fig-8: Total biomass of castor under different levels of elevated CO2 (700, 550ppm) over chamber control and open control**



### 2.2.9 Yield

The yield parameters *viz.,* spike length, spike dry weight, number of capsules, capsule dry weight, seed weight and 100 seed weight were recorded per three plants for each treatment (Table- 1, 2 & 3) in both generations and open control grown plants. The increment in seed yield was more under 700ppm when compared to 550ppm over the Ch-control. The yield parameters like spiking length, spiking dry weight, and seed weight were more under 700ppm followed by 550ppm, Ch-Control. Number of capsules, capsule dry weight was more under 550ppm followed by 700ppm and Ch-Control.
At 700 ppm level the oil content was more when compared to 550ppm and Ch-Control in second generation.

**Table-1**: First generation bean yield of castor under different levels of elevated $CO_2$ (700, 550ppm) over chamber control and open control.

| **S. No** | **Parameters** | **Conditions** | | | |
|---|---|---|---|---|---|
| | | **700ppm** | **550ppm** | **Ch-Control** | **Open Control** |
| 1 | Total plant biomass (g) | 84.9 | 104.9 | 81.5 | 70.3 |
| 2 | Spike length (cm) | 19.8 | 19.8 | 15.5 | 10.4 |
| 3 | No. of Capsules | 22.8 | 33.1 | 19.5 | 14.3 |
| 4 | Capsule dry weight (g) | 25.5 | 25.3 | 29.1 | 17.7 |
| 5 | **Seed wt. (g)** | **8.3** | **8.6** | **4.6** | **7.0** |
| 6 | Husk wt. (g) | 17.2 | 16.7 | 24.5 | 10.8 |
| 7 | 100 Seed wt. (g) | 21.8 | 26.7 | 24.0 | 22.3 |
| 8 | Harvest Index % | 9.7 | 8.2 | 5.6 | 9.9 |

**Table-2**: Second-generation bean yield of castor under different levels of elevated $CO_2$ (700, 550ppm) over chamber control and open control.

| S. No | Parameters | Conditions | | | |
|---|---|---|---|---|---|
| | | 700ppm | 550ppm | Ch-Control | Open Control |
| 1 | Total plant biomass (g) | 85.5 | 92.6 | 66.3 | 113.4 |
| 2 | Spike length (cm) | 13.3 | 16.6 | 10.6 | 15.4 |
| 3 | No. of Capsules | 24.4 | 22.4 | 26.4 | 23.1 |
| 4 | Capsule dry weight (g) | 26.5 | 26.8 | 22.3 | 28.8 |
| 5 | Seed wt. (g) | 13.4 | 10.8 | 8.8 | 8.1 |
| 6 | Husk wt. (g) | 13.1 | 16.0 | 13.6 | 20.7 |
| 7 | 100 Seed wt. (g) | 20.7 | 23.1 | 21.0 | 22.3 |
| 8 | Harvest Index % | 15.6 | 11.6 | 13.2 | 7.2 |

**Table-3:** Castor bean yield of last season seed (developed under different levels of elevated $CO_2$) under open field condition.

| S. No | Parameters | Conditions | | | |
|---|---|---|---|---|---|
| | | 700ppm | 550ppm | Ch-Control | Open Control |
| 1 | Total plant biomass (g) | 108.1 | 82.3 | 95.1 | 113.4 |
| 2 | Spike length (cm) | 19.3 | 18.0 | 9.9 | 15.4 |
| 3 | No. of Capsules | 16.9 | 14.7 | 21.6 | 23.1 |
| 4 | Capsule dry weight (g) | 25.2 | 28.5 | 33.6 | 28.8 |
| 5 | Seed wt. (g) | 10.2 | 9.8 | 7.1 | 8.1 |
| 6 | Husk wt. (g) | 15.0 | 18.7 | 26.5 | 20.7 |
| 7 | 100 Seed wt. (g) | 24.3 | 22.7 | 21.3 | 24.8 |
| 8 | Harvest Index % | 9.4 | 11.9 | 7.5 | 7.2 |

### 2.2.10 Conclusions

- The growth and yield response of castor crop at first and second generation levels showed positive response to both enhanced $CO_2$ levels
- The response of second generation crop was similar to the last season trend and all the growth characters showed maximum response at 700 ppm $CO_2$
- The difference in response was minimized among the treatments when the last season seed from different treatments grown under open field conditions
- The seed yield of primaries and 100 seed weight was more under 700 ppm when compared with 550ppm
- The responses of different components to two levels of enhanced levels of $CO_2$ are different. At 550ppm more increment in economic yield than total biomass resulted higher HI
- Both elevated $CO_2$ levels increased the oil content and the response was more prominent in second-generation crop.

## 3.0 Impact of elevated $CO_2$ and temperature on insect-plant interactions

The following activities were undertaken during the project period.

1) Basic studies on impact of elevated $CO_2$ and temperature on groundnut (*Spodoptera litura*) and castor (*Spodoptera litura* and *Achaea janata*)
2) Bio chemical analysis of leaf samples
3) Development of Pest scenarios

**Impact of host mediated factors and $CO_2$ /temperature on the Dryland pests**

Experiments were conducted to evaluate the impact of elevated $CO_2$ on castor semilooper (*Achaea janata*) and tobacco caterpillar (*Spodoptera litura*) on castor and groundnut. The host plants viz. groundnut and castor were grown under ambient as well as elevated carbon dioxide conditions. Thus four treatments were adopted to study the impact of host mediated effect (plant growing conditions) on insects and were maintained in open top chambers. The crops were grown under four different conditions viz., ambient (365 ppm $CO_2$), elevated $CO_2$ (550 and 700-ppm) and chamber without elevated $CO_2$.Insect larvae were reared under two different conditions viz., 550 ppm CO2 with 27 $^0$ C and 365 ppm with 25 $^0$ C.

For each treatment, 10 larvae were selected and reared on foliage taken from the above treatments. The larval parameters namely larval length and weight, % of feeding, weights of faecal matter and leaves, larva, pupa and adult periods, hatchability of eggs were recorded.

**Consumption rate of *S. litura* and *A. janata* on castor**

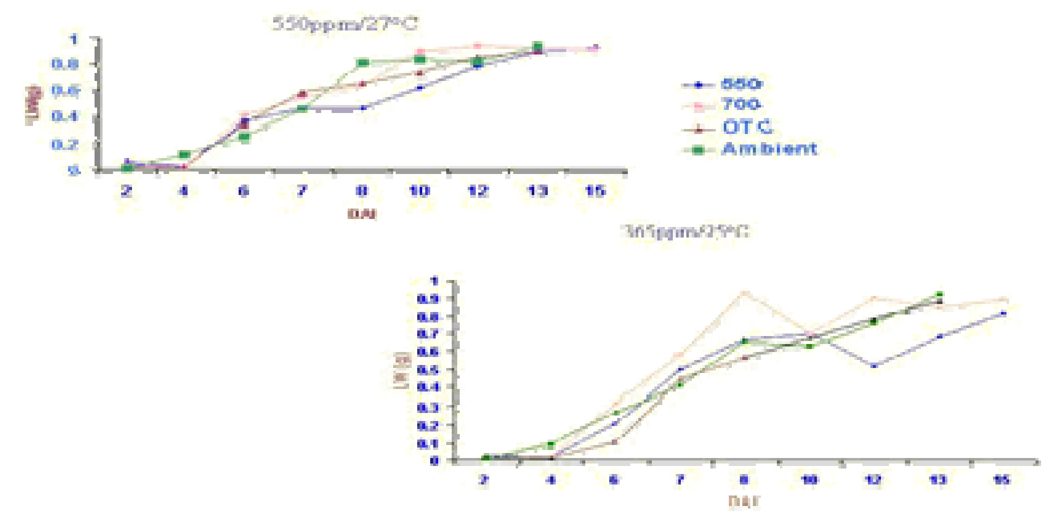
**A.janata**

The impact of elevated $CO_2$ on various larval weight of *A.janata* on castor was depicted in the Fig. 1. The larval weight was more when larvae were allowed to feed on foliage obtained from castor grown under elevated $CO_2$ treatment than the rest of the treatments. The consumption rate was more than 20%. The larval weight was more in the elevated treatments. The lengths of larva, the faecal matter released were also altered among the treatments. The larval duration was increased by 1-2 days in case of larvae, which were reared on foliage raised in the elevated $CO_2$ treatments.

***S.litura***

The consumption pattern of *S. litura* was more (50%) on both the hosts (castor and groundnut) under elevated $CO_2$ conditions 700 and 550 ppm than ambient and chamber conditions. The larval weights were also increased by 20-30%.

Fig 1.Impact of elevated $CO_2$ on *A. janata* –Larval weights



**Impact of elevated CO2 and temperature on indices of insect performance**

Using the data on larval parameters various indices of insect performance were determined gravimetrically after Waldbauer (1968). Briefly;
a) Relative Growth Rate (RGR)= *mg* larval biomass gained/average *g* insect body weight/day
b) Relative Consumption Rate (RCR)= *mg* foliage ingested / average *g* insect body weight /day
c) Growth Efficiency (ECI)= *mg* biomass gained / *mg* foliage ingested x 100
d) Conversion efficiency (ECD)= *mg* biomass gained /(*mg* foliage ingested- *mg* frass produced) x100
e) Approximate Digestibility (AD)= (*mg* foliage ingested- *mg* frass produced) x *mg* Foliage ingested x100

***A.janata***

The impact of elevated $CO_2$ and temperature on various insect performance indices of *A.janata* was presented in Table .1.The main effects of host mediated factors and $CO_2$ concentration and their interaction, influenced most indices of *A.janata* performance. Substantial differences were noticed among the treatments. Larvae survived very well on all the treatments.
Development time increased 20-25% in larvae fed elevated CO2.The two factors viz., host mediated factors significantly influenced all indices of *A.janata*. and second factor $CO_2$ concentration also significantly influenced the ECD and AD indices.
The impact of elevated $CO_2$ on relative growth rates of insect was strongly influenced by both host mediated factor (elevated $CO_2$) and direct effect of $CO_2$ and temperature decreasing in larvae fed castor.
Final larval masses reflected trends in growth rates for enriched $CO_2$ treatments. Food consumption rates varied in response to host mediated factor and $CO_2$ treatment. Both relative consumption rates and total consumption varied also significantly and larvae consumed more than the ambient and chamber treatments. Changes in *A.janata* growth rates can be attributed to variation in food processing efficiencies.
High $CO_2$ foliage was 8 % more digestible than ambient $CO_2$ foliage. Although efficiency of conversion digested food (ECD) appeared to decrease 40% markedly in larvae fed high $CO_2$ .ECD values decreased moderately for larvae fed elevated $CO_2$.Larvae were much less efficient in converting digested castor in to body mass.
Finally efficiencies of ingested food ECI for larvae on high $CO_2$ foliage decreased substantially for insects fed on elevated castor.
Similarly the significant differences were observed among indices of *S.litura* performance. The RGR of larvae varied significantly among treatments and host mediated factors and also insect rearing conditions (Fig 2.)

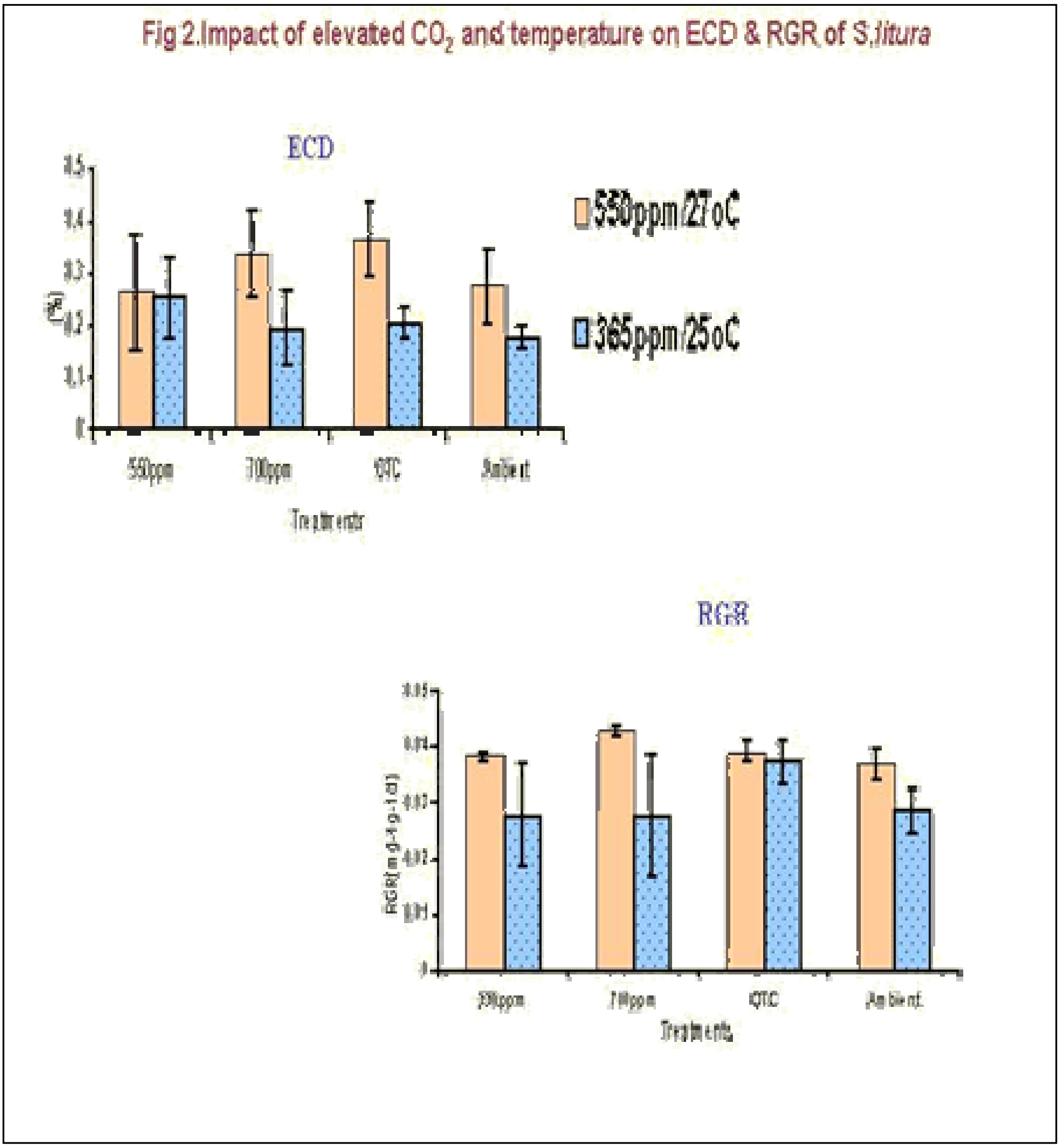


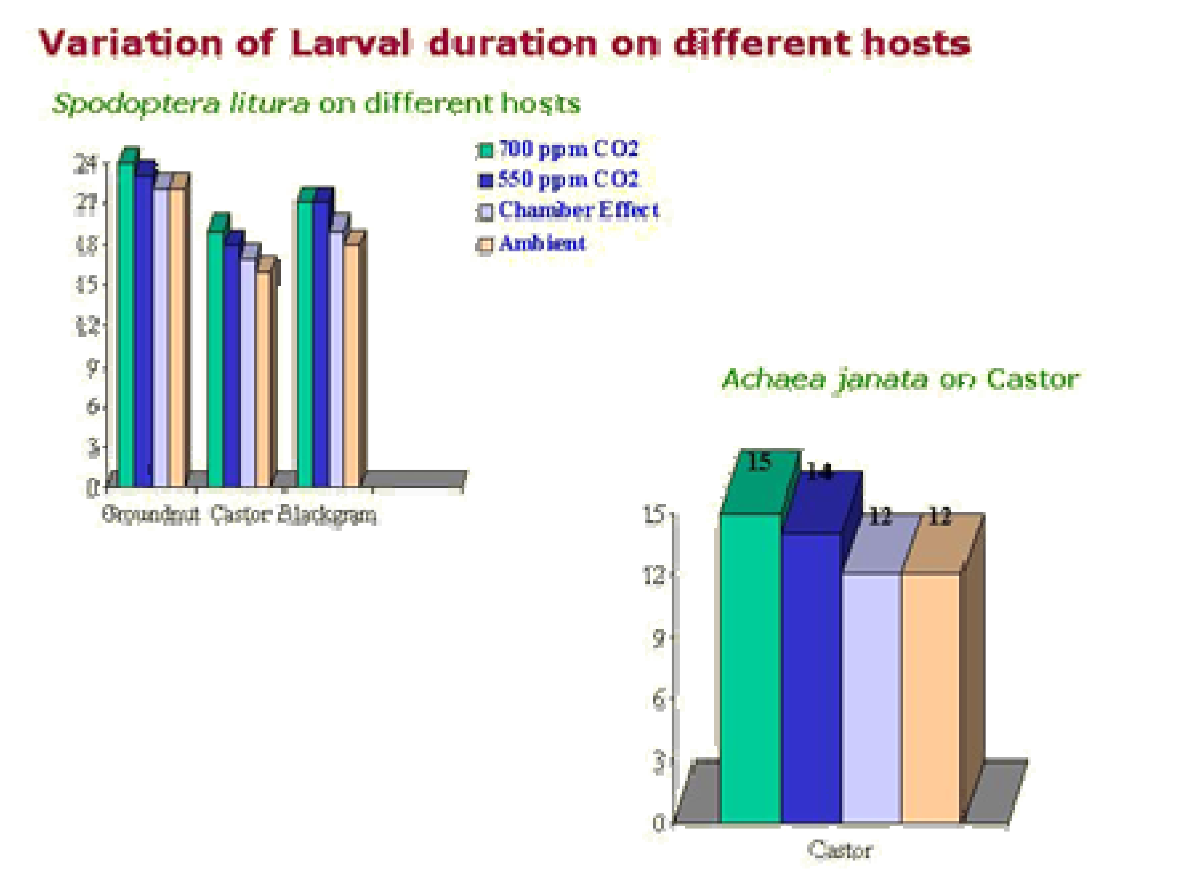
Fig 2.Impact of elevated $CO_2$ and temperature on ECD & RGR of S.litura
ECD
(%)
550ppm/27oC
365ppm/25oC
550ppm
700ppm
Ambient
Treatments
RGR
Ambient
Treatments

Table 1.Impact of elevated $CO_2$ and temperature on indices of Achaea janata

| Treatments: Insect rearing condition | Treatments: Plant growing condition | RGR (mg/g/d) | RCR (mg/g/d) | ECD (%)` | AD (%) | ECI (%) |
|---|---|---|---|---|---|---|
| $Co_2$550ppm+27°C | $Co_2$550 | 0.062 | 1.11 | 6.5 | 87.7 | 5.7 |
| $Co_2$550ppm+27°C | $Co_2$700 | 0.062 | 1.173 | 6.4 | 85.6 | 5.4 |
| $Co_2$550ppm+27°C | OTC | 0.074 | 0.874 | 10.3 | 82.9 | 8.5 |
| $Co_2$550ppm+27°C | Ambient | 0.078 | 0.882 | 11.8 | 74.6 | 8.8 |
| $Co_2$365ppm +25°C | $Co_2$550 | 0.056 | 1.082 | 6.2 | 87.4 | 5.3 |
| $Co_2$365ppm +25°C | $Co_2$700 | 0.063 | 1.417 | 5.1 | 88.8 | 4.5 |
| $Co_2$365ppm +25°C | OTC | 0.073 | 1.045 | 7.8 | 90.4 | 7 |
| $Co_2$365ppm +25°C | Ambient | 0.076 | 0.787 | 10.7 | 84.4 | 9.7 |
| | | | | | | |
| SEm | | 0.003 | 0.129 | 1.01 | 2.5 | 0.8 |
| L SD at 0.05 | | 0.006 | NS | 2.02 | NS | NS |
| *Host mediated factor 1* | | | | | | |
| $Co_2$550 | | 0.059 | 1.094 | 6.4 | 87.5 | 5.5 |
| $Co_2$700 | | 0.062 | 1.295 | 5.7 | 87.2 | 5 |
| OTC | | 0.073 | 0.959 | 9 | 86.6 | 7.8 |
| Ambient | | 0.077 | 0.835 | 11.7 | 79.5 | 9.3 |
| | | | | | | |
| SEm | | 0.002 | 0.091 | 0.7 | 1.8 | 0.6 |
| L SD at 0.05 | | 0.004 | 0.195 | 1.5 | 3.8 | 1.2 |
| *Direct effect of CO2 and temp-factor2* | | | | | | |
| $Co_2$550ppm+27°C | | 0.069 | 1.009 | 8.8 | 82.7 | 7.1 |
| $Co_2$365ppm +25°C | | 0.067 | 1.083 | 7.6 | 87.7 | 6.6 |
| | | | | | | |
| SEm | | 0.005 | 0.065 | 0.5 | 1.3 | 0.4 |
| L SD at 0.05 | | 0.011 | NS | 1.1 | 2.7 | NS |
| Cv% | | 4.87 | 15.14 | 14.98 | 3.67 | 14.08 |

**Variation of larval duration**

The larval duration of both *A.janata* (monophagous) and *S.litura* (polyphagous) insects varied when larvae were allowed to feed on different hosts when grown under elevated $CO_2$ conditions. The larval duration was increased by 2-3 days under elevated $CO_2$ conditions. The larval duration was more incase of groundnut (22-24 days) followed by blackgram (21 days) and castor (19 days) crops under elevated $CO_2$ (700-550 ppm) (Fig 3).



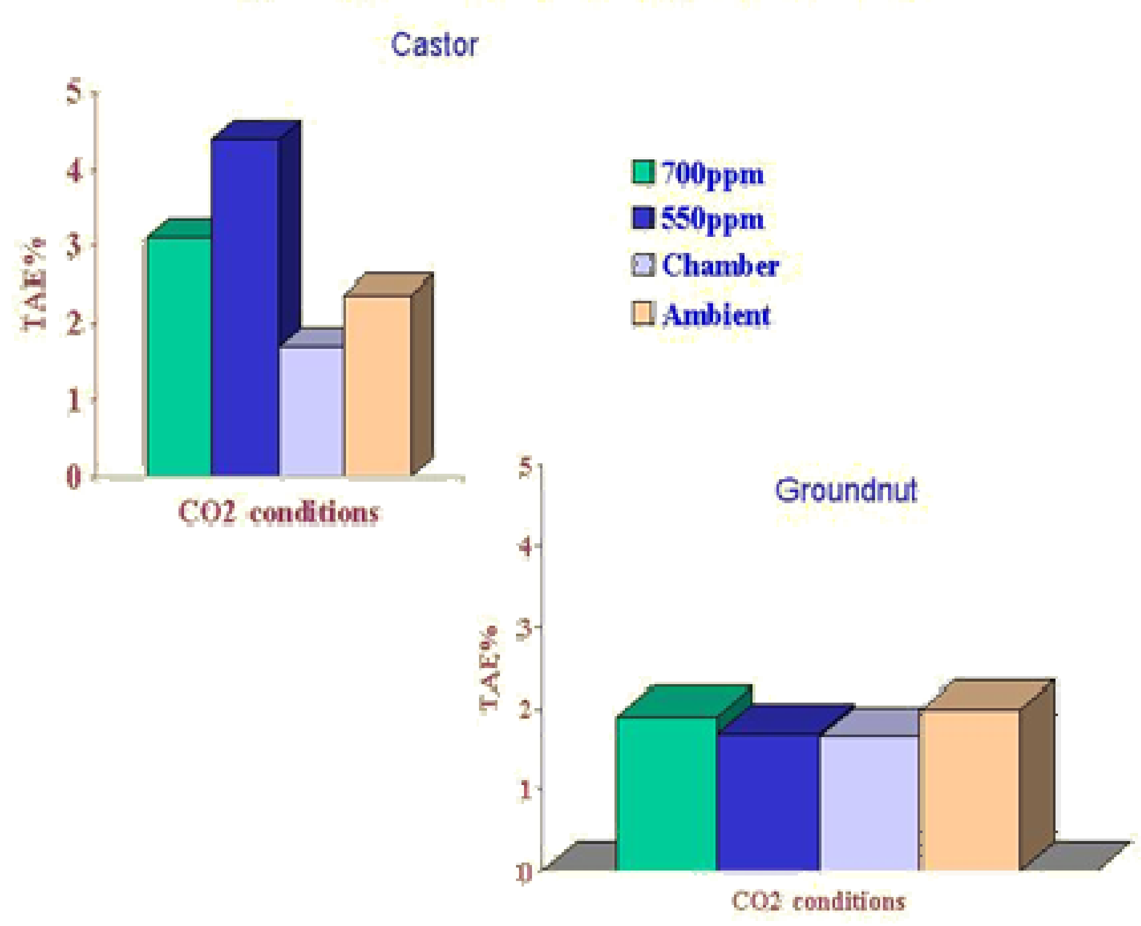
**Biochemical analysis of leaf samples:**

Foliar tissue from each plant used in the feeding experiment was analyzed for polyphenols. For total phenols and condensed tannins analysis leaf samples were dried at 40 $^0$ C for 48 hrs. Dried leaf samples were ground to powder. For total phenols, the Prusian blue assay was used with standard curve absorption at 725 nm established with commercial tannic acid. Total phenolics were analyzed using the Folin-Cicolteu reagent technique as described by Singleton and Rossi (1965). For this determination, tannic acid was used in the development of a standard curve.

This analysis was used for comparisons between treatments of relative quantities of carbon-based phenolics expressed as percentage tannic acid equivalents (Fig 4).

The polyphenol concentration was more in castor under elevated $CO_2$ than the rest of the treatments. But in case of groundnut variation of polyphenols was not much noticed among the treatments.

Fig 4.Polyphenols in Castor & groundnut leaves



**Pest scenarios:**

Pest scenarios were predicted using several thumb rules obtained from earlier projects of NATP and institute projects of CRIDA .The successful and standard thumb rule developed for Helicoverpa was used to predict pest incidence .The thumb rule indicate that " if rainfall during the months of June-Sept is below the normal and rainfall during the month of November is above the normal then pest incidence will be severe on pulses." The precipitation levels were estimated and presented in table 2. Results indicated that the predicted pest incidence would be low during (2020) and moderate during 2050 and 2080 years of Hyderabad area. Similarly the pink bollworm incidence was also estimated and presented in Table 3. The results indicated that the level of population would be moderate in both 2020 and 2071; severe in 2086 and 2100 years.

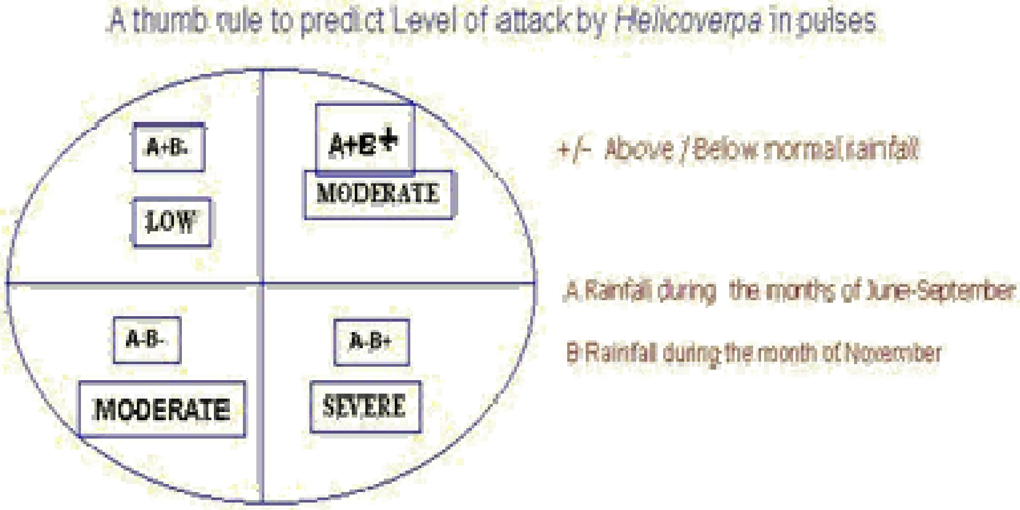



Table 2.Prediction of Helicoverpa based on thumb rule

| | Precipitation | | Pest Scenario |
|---|---|---|---|
| | June-Sept | November | |
| Normal | 523.6 | 10.7 | |
| 2020 | 620.1 + | 8.1 - | Low |
| 2050 | 739.2 + | 16.5 + | Moderate |
| 2080 | 619.5 + | 12.9 + | Moderate |

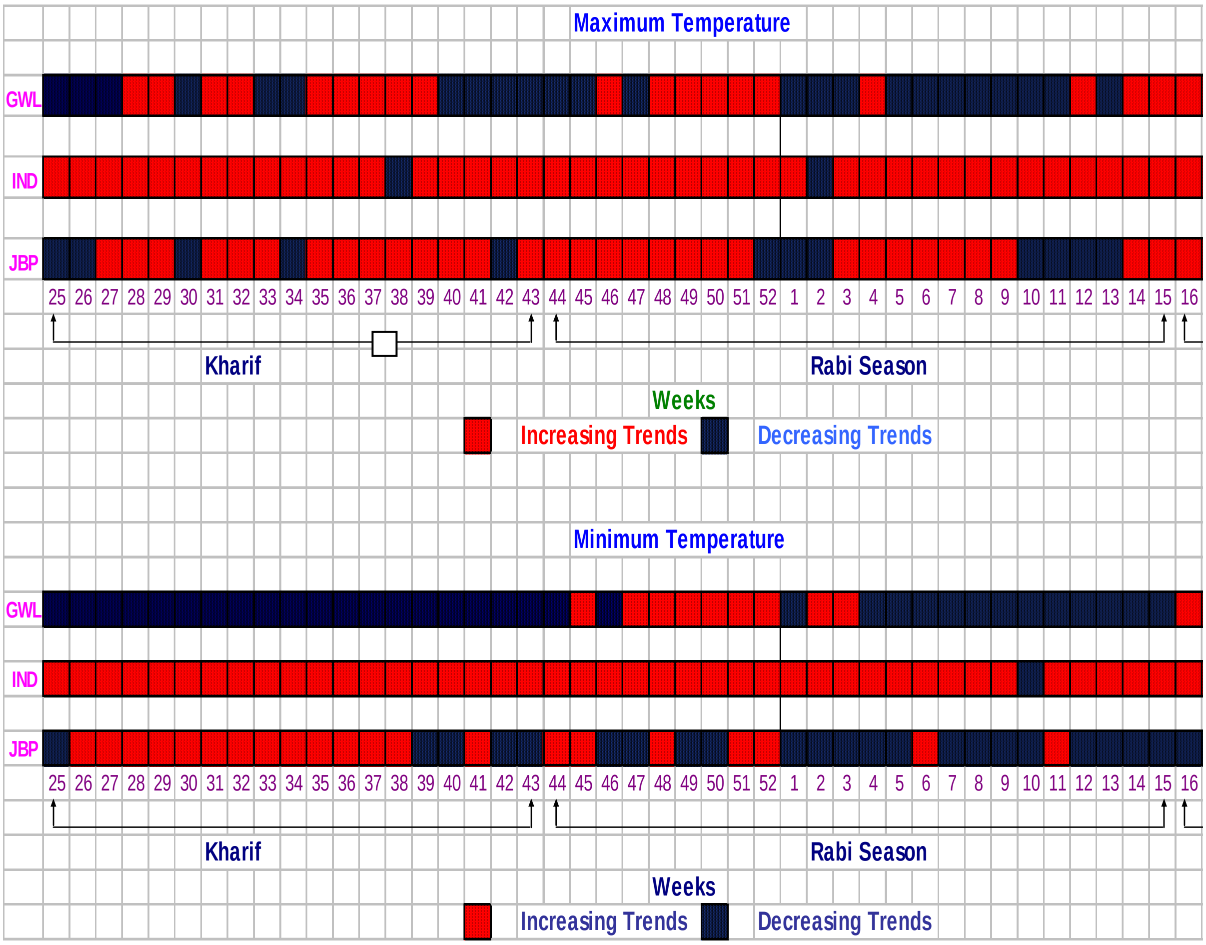
## Jawahar Lal Nehru Krishi Vishwavidyalaya, Jabalpur

During the report period efforts were mainly focused on studies related with the climatic characterization, impact studies on crops, and physiological studies under controlled and field conditions including multi-location trials to study crop responses to diiferent thermal regimes. Socio-economic studies in tribal districts to assess the impact of climate change on livelihood security and vulnerability of tribal population to climate change were also undertaken. Following specific results of practical/scientific values are reported.

**Climatic Characterization-**

**A. Jabalpur, Indore and Gwalior:** Changes in temperature and precipitation patterns together with occurrence of extreme events are major threat to future food security due to climate change. After collection of long term data for more locations of Madhya Pradesh, climatic characterization was done for long-term trends and occurrence of extreme events for precipitation and temperature in relation to crop growth phases as climate change related occurrence of these extreme events can have serious consequences for agricultural production. A comparison of these trends for different places reveals important trends that can be useful for making future changes in cropping patterns. For example, long term trends in weekly temperatures for Jabalpur and Gwalior reveal a very different trend; whereas in Gwalior there is a cooling trend for most part of crop growth period but Jabalpur has a warming trend during kharif and cooling trends during rabi season. These places also vary remarkably in terms of occurrence of extreme events of precipitation and temperature. (**Figure-1**).

**Figure-1: Climatic characterizations of different environments (Temperature in $^0$C):**



**B. Pachmarhi Biosphere Reserve:** The trend analysis of different climatic variables such as maximum temperature, minimum temperature and rainfall were carried out to assess the temporal; and spatial variation in the climate in three different altitudes of Pachmarhi Biosphere Reserve namely Pachmarhi (Top), Chhindwara (middle) and Powerkheda (bottom). Remarkably significant variations were found in the trend of maximum temperature in kharif, rabi and summer in these altitudes. Hence, such temporal and spatial variability behavior of these climatic variables are going to influence the existing biodiversity in these altitudes which may be in terms of shift in the vegetation or in affecting the accumulation of active ingredients of some economically useful plants by differential gene expression due to genotype and environment interaction, which needs further validation (**Fig-2A, 2B & 2C**).

**Figure-2A**

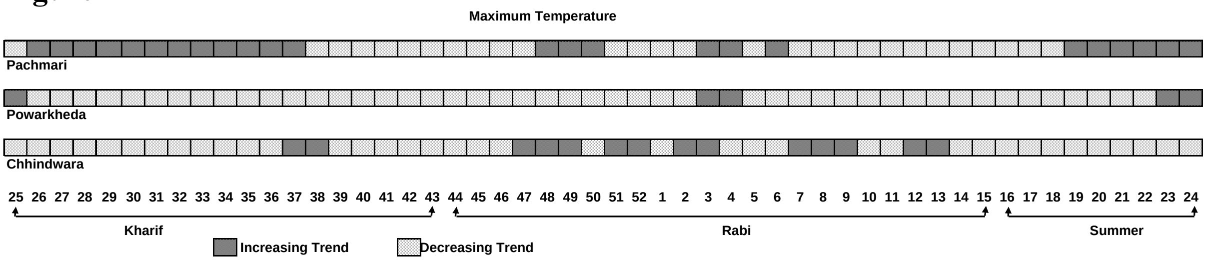



**Figure-2B**

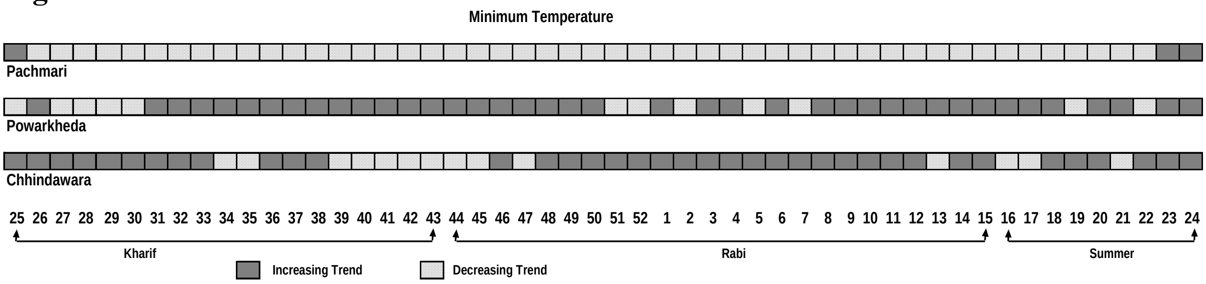
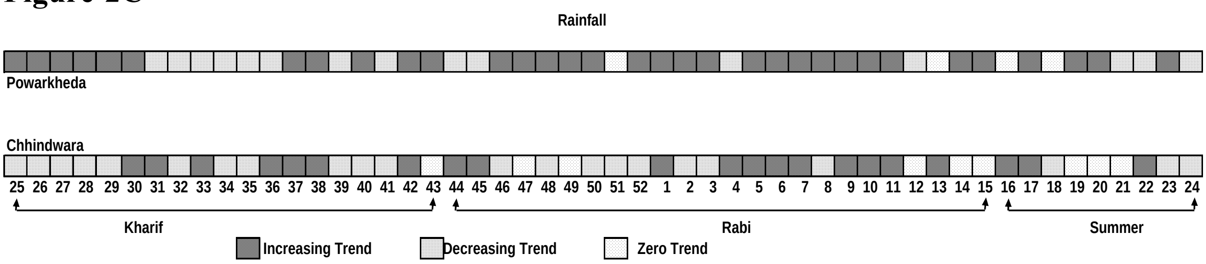



**Figure-2C**




**Trend Analysis for Crop Productivity –**

A. **Soybean**- Trend analysis for major crops of the state was done in relation to temperature and precipitation. The normalized yields were compared with normalized rainfall and temperature to assess the sensitivity of crop productivity with changes in these important weather variables. In soybean for example, productivity at Jabalpur is negatively associated with increasing rainfall whereas at Indore there is an increase in yield with increased precipitation. Thus, in future with increased precipitation soybean may not be a viable option for places like Jabalpur that are in high rainfall zone **(Fig-3A, 3B & 3C).**

**Fig-3A: Relationship between Normalized yield and Rainfall deviation in Soybean at Indore**

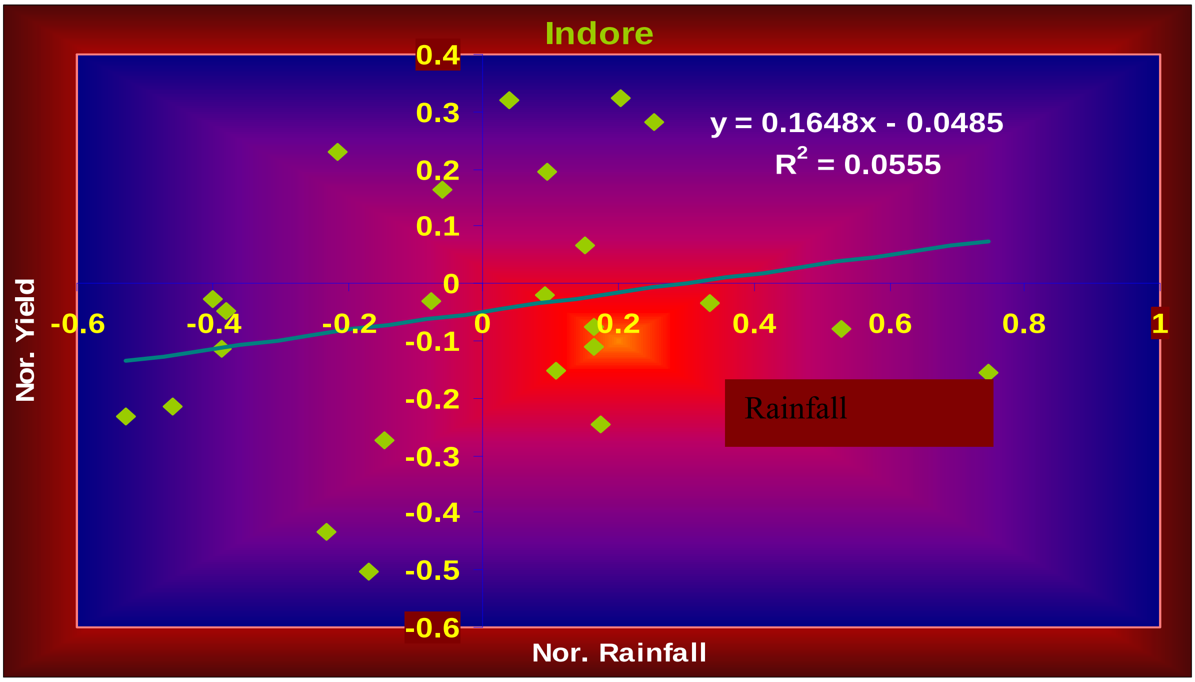



**Fig-3B: Relationship between Normalized yield and Rainfall deviation in Soybean at Jabalpur**

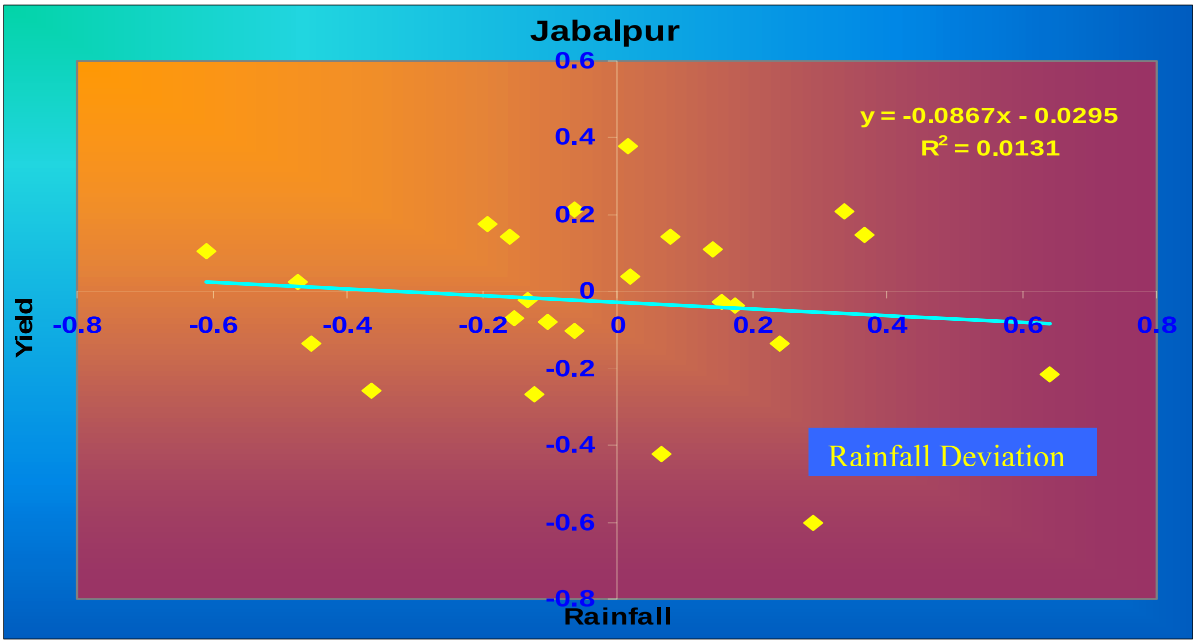
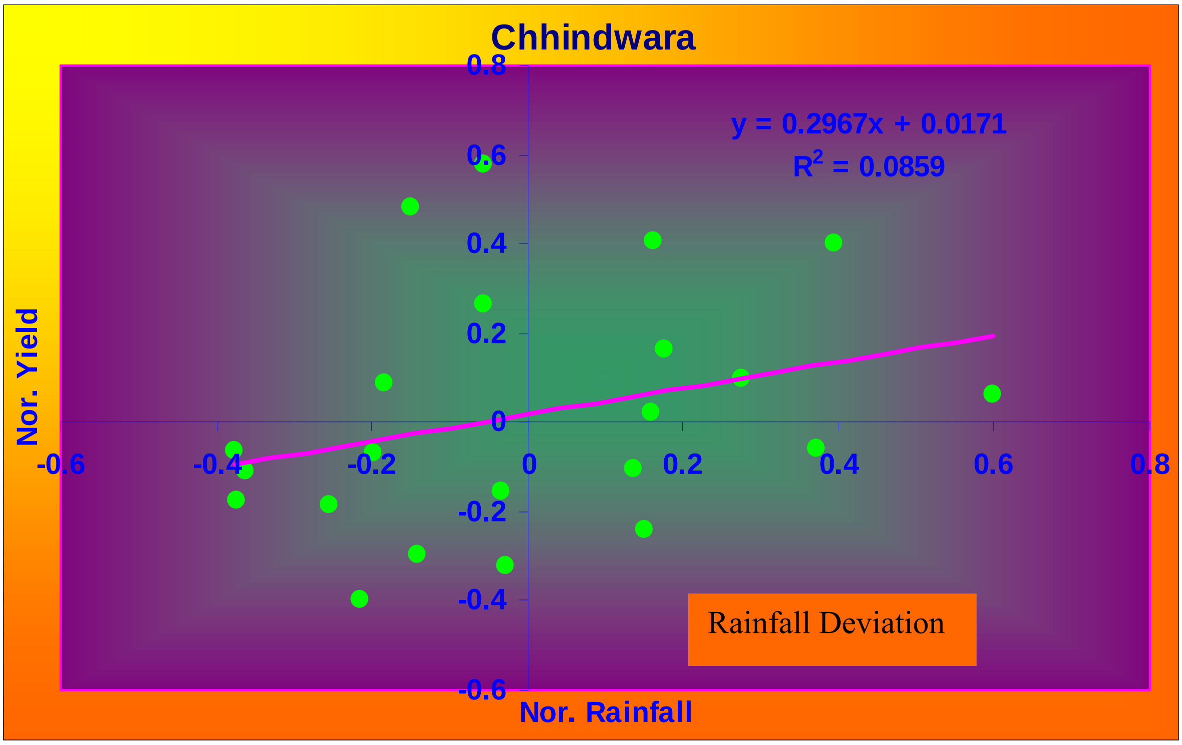


**Fig-3C: Relationship between Normalized yield and Rainfall deviation in Soybean at Chhindwara**




**B. Wheat:** Climate change will have direct impact on the agricultural productivity because of alterations in temperature and rainfall. Long term trend analysis of crop productivity revealed that vulnerability of wheat productivity due to increasing maximum temperature is location specific and cannot be generalized as a whole. The declining wheat productivity in certain environments is attributed to the superimposition of critical reproductive phase with the increased higher temperature stress and interference with the minimum vernalization effect which is a *sine-qua-non* for the floral bud initiation. Similarly, it was found that there is a direct relationship between the rainfall (winter) and yield of wheat. However, impact of minimum temperature on the productivity was found to be negligible (Fig-4A, 4B, 4C & 4D).

**Fig-4: Relationship between Normalized yield deviations and maximum temperature deviations in different wheat growing regions of Madhya Pradesh:**

**Fig-4A**

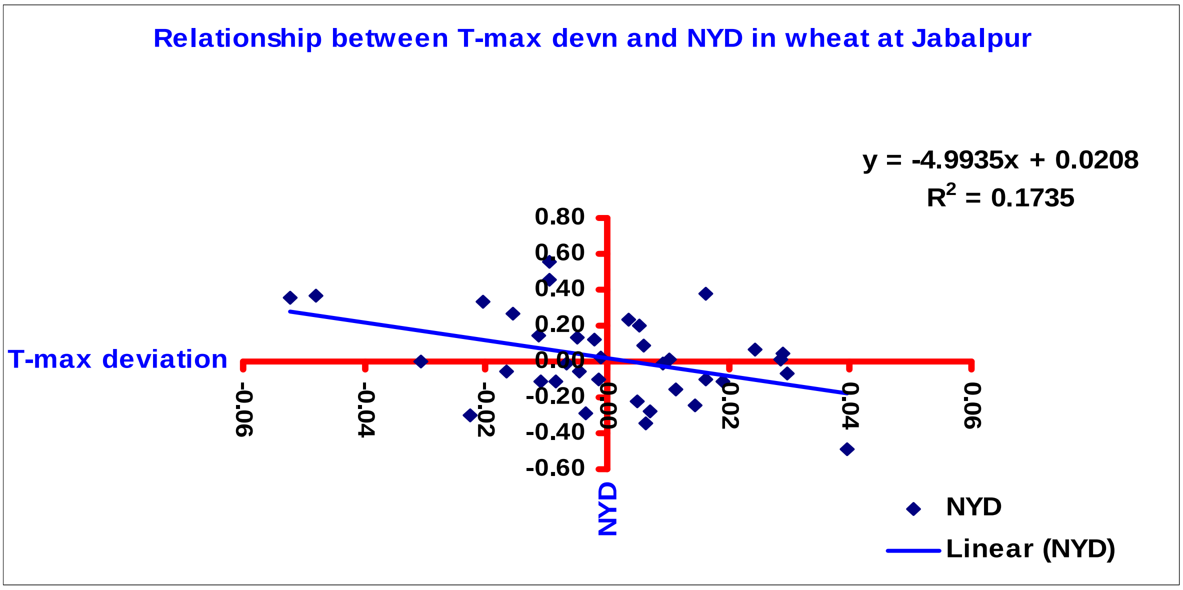



**Fig-4B**

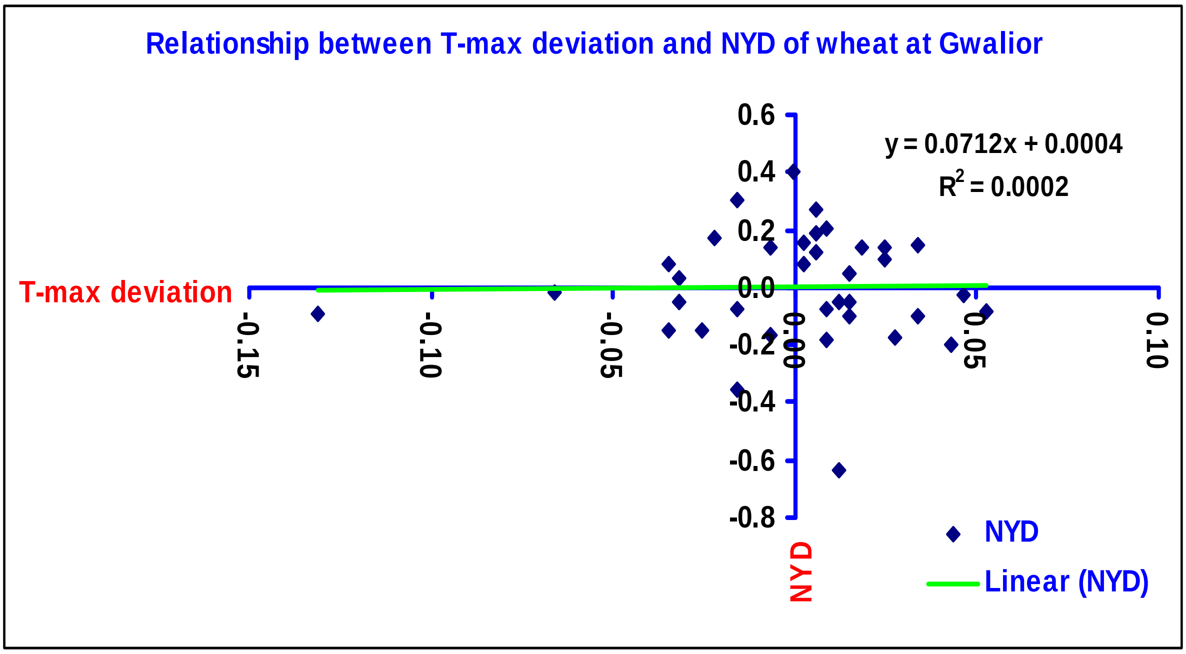


Fig-4C

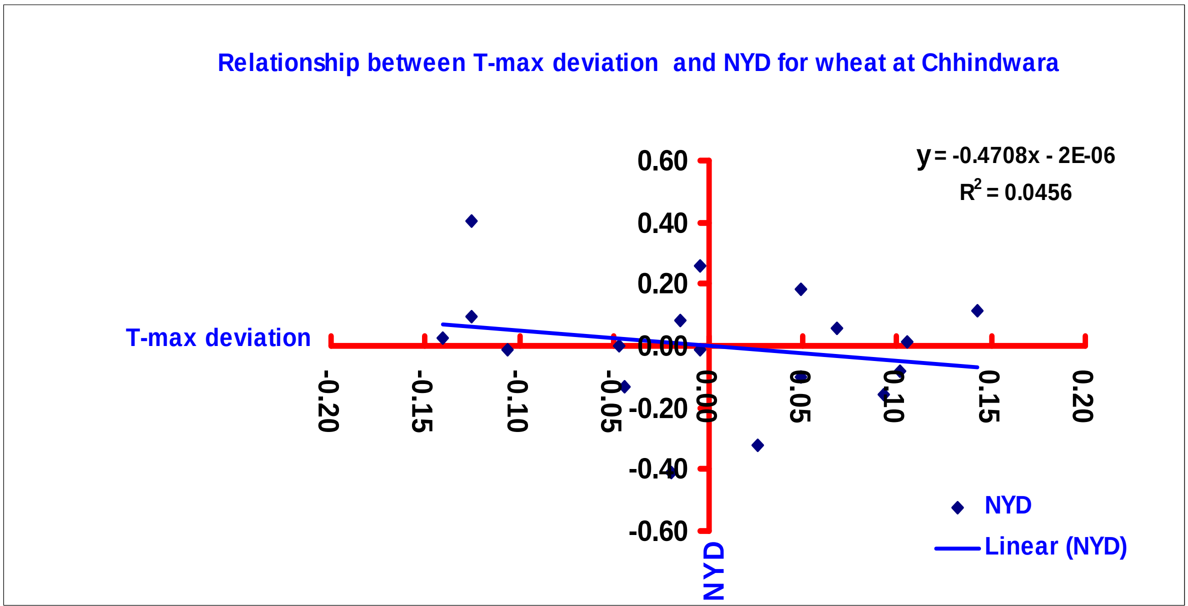
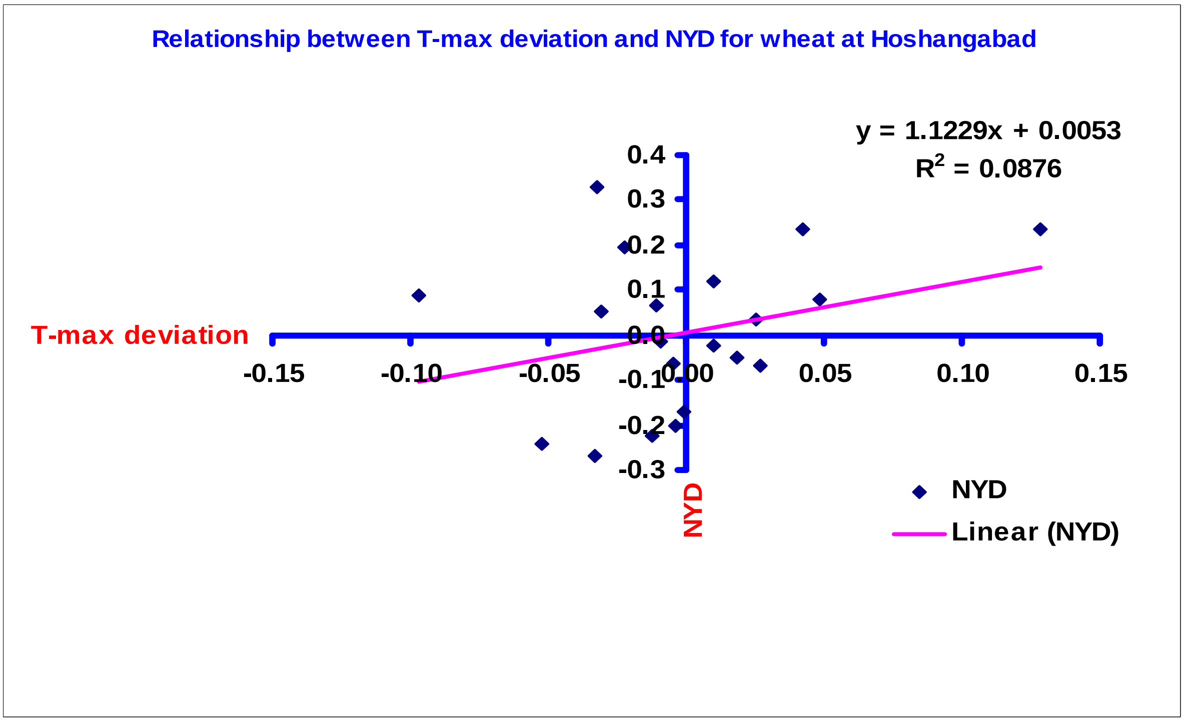



Fig-4D




**C. Chickpea:** Adverse impact of increased temperature was also observed on the yield of chickpea in all the environments, which is mostly due to the reduction in flowering, fruiting, and pollination due to higher temperature stress. Hence, adaptive responses to combat above narrated problems in Madhya Pradesh conditions require genetic and agronomic interventions to reinforce food, livelihood, nutritional and economic security (**Fig-5A to 5D)** in rainfed agro-ecosystem**.**

**Fig-5: Relationship between Normalized yield deviations and maximum temperature deviations in different Chickpea growing regions of Madhya Pradesh:**

**Figure-5A**

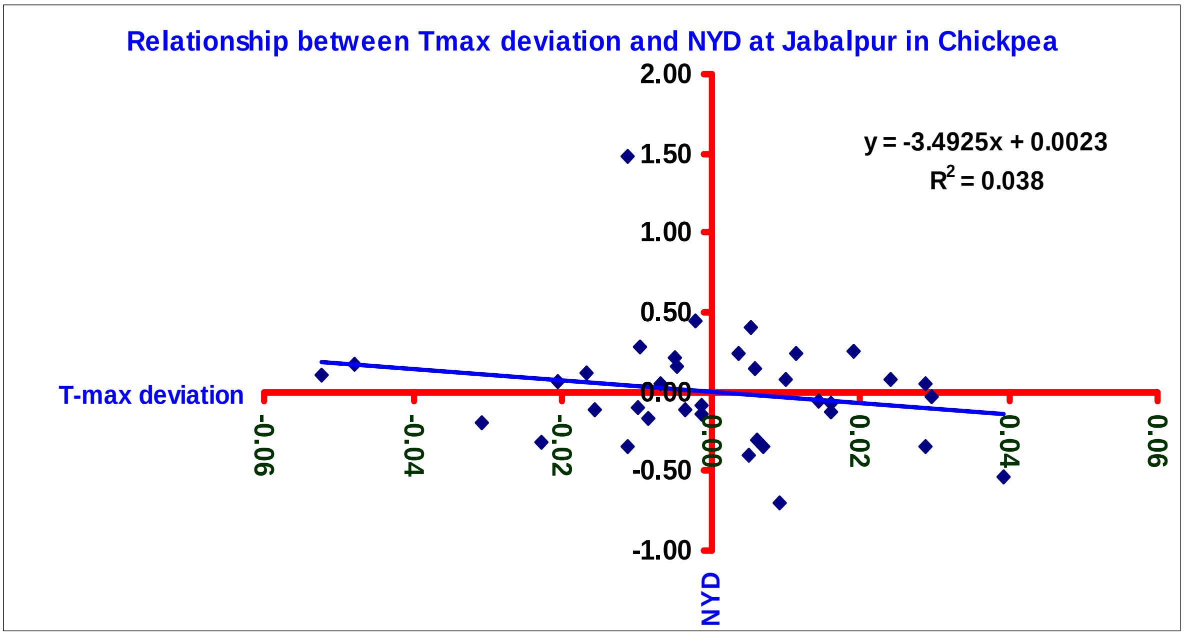



**Figure-5B**

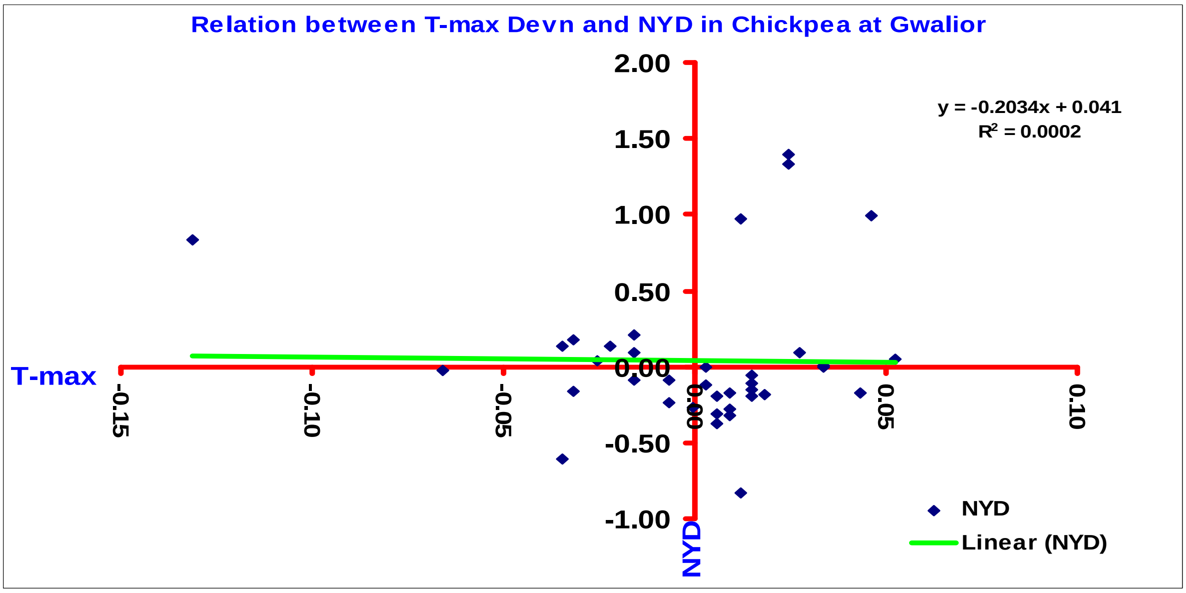


**Figure-5C**

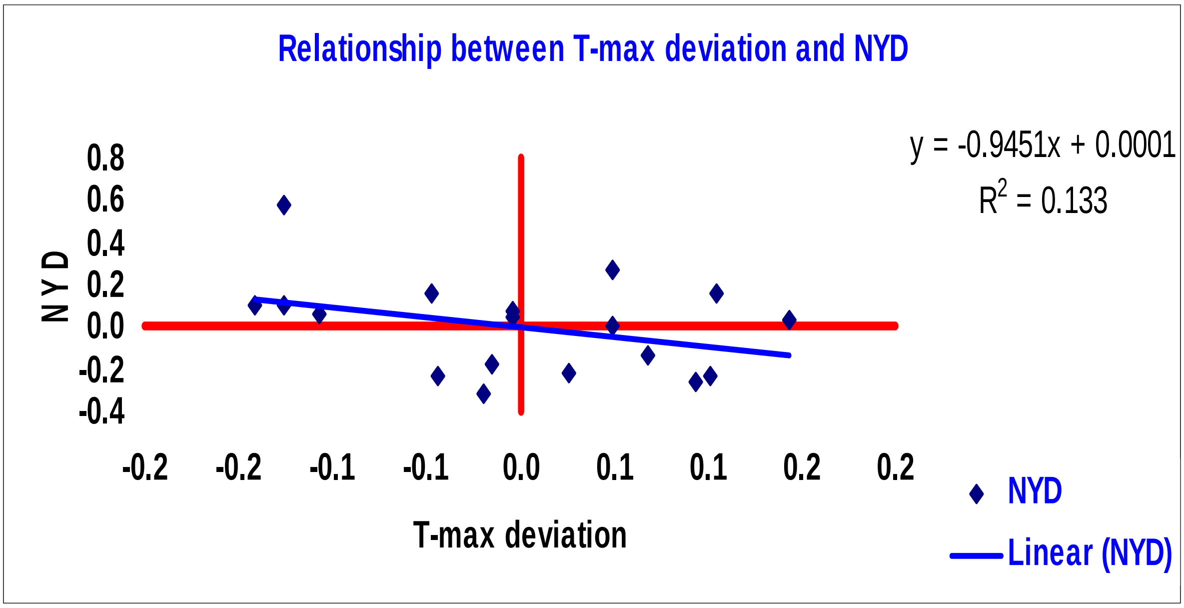
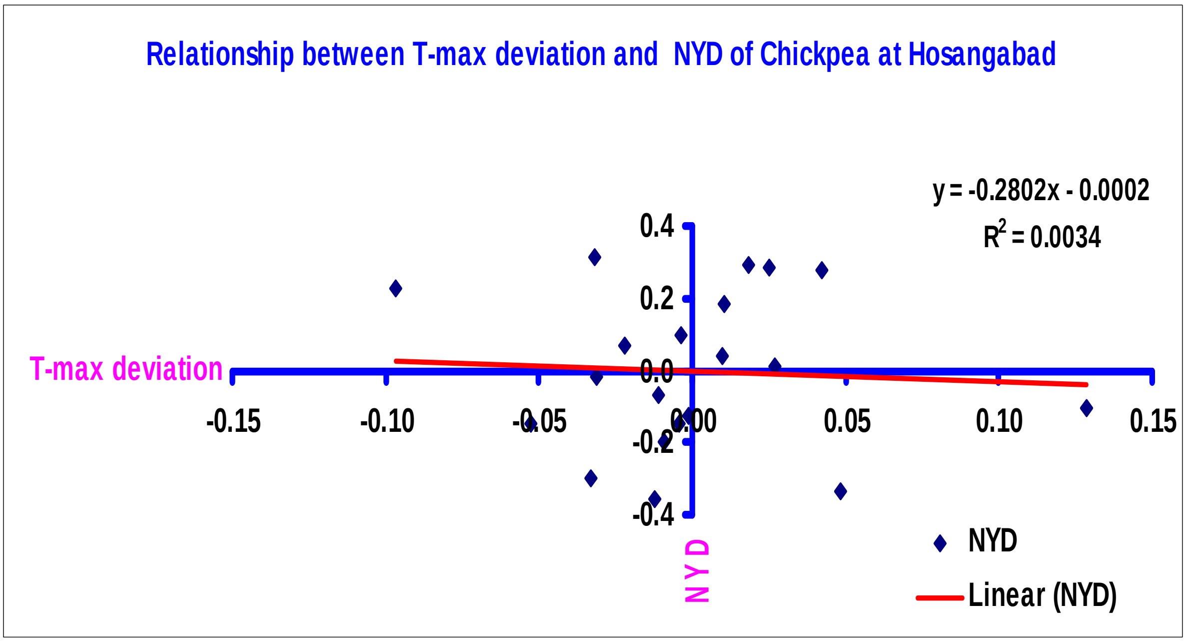



**Figure-5D**




**Biological Indicators for Climate Change:**

- One remarkable indicator that has been recorded for the last more than 10 years is flowering in Mango in this region. During last decade early flowering in mango has been a common feature, which has been recorded in the university farm. It is believed to be triggered with generally warmer winters.
- Since, last 4-5 years late flowering (up to Feb end) has been observed in *Mahua (Madhuca indica)*, which is delayed by one and half month. This resulted into decrease in overall production of this commodity by 30-40 %.

- As a regular phenomenon of alternate bearing in the traditional varieties of mango now having bearing every year from last 3-4 years being a beneficial impact of climatic change need scientific validation.
- The traditional dry land fruit *Jamun (Syzizium cummini)* is showing delayed fruit maturity, which reduces its pulp.
- Overall production of deshi Aonla is increasing since last 2-3 years in the Satpura plateau agro-climatic zone (Chhindwara & Betul districts).
- *Local varieties of Guava (Psidium guava)* are having 3-4 times flowering and fruiting in a year since last 2 years; while earlier it was twice in a year.

**Altitudinal Shifts in Species Diversity –** Species diversity evaluation (*in-situ)* under altitudinal gradient at Pachmarhi Biosphere Reserve (PBR) has revealed an upward shift in certain plant communities. Although there are no systematic long term records of altitudinal distribution of medicinal plant species, however, a survey conducted in the Pachmarhi Biosphere Reserve and an interaction with locals has revealed that many species have disappeared from lower altitudes and now only found at higher elevations. Many other factors, like over exploitation, population pressure etc. may have also contributed to this upward shift but it is plausible to suggest that rising temperature is also a major factor in this shift.

**Physiological Studies on Medicinal Plants -** Medicinal plants have not received much research attention in the past and therefore, there is limited information available on eco-physiological aspects. In order to assess the likely impact of climate change on this special group of plants and their vulnerability to climate change, these studies are important. Field studies were conducted through staggered plantings and multi-location plantings to study the responses of some of the important species of medicinal plants to temperature. Laboratory studies were also conducted to characterize for their thermal responses to emergence.

**Quality Analysis of Medicinal Plants: To Evaluate the Differential Response of Biochemical Profile and Alkaloid of Selected Medicinal Plants to Climate Change:** Experimental results revealed that there is a improvement in the quality profile of medicinal plants with increased temporal and spatial climatic variability which may be attributed to the tolerant behavior of these plants to climate change due to acquisition of adaptive traits during the course of evolution. Further, it was observed that there is a significant increase in the quantum of secondary metabolite production with increase in higher temperature stress. Hence, these crops could be taken as a component crop in crop diversification programme in future climate change scenario to have economic and livelihood security of vulnerable groups (tribals, small and marginal farmers) (Fig**-6 to 10**).

It is also interesting to observe that staggered date of sowing in Ashwagandha induces incremental change in the quality of chemical components which increased Withaferine A in early date of sowing i.e. October 25 and Withanoide B in late sowing i.e December 12 with no such changes in November sowing. The Chandrasur has shown maximum gain of synapic acid (%) in the December sowing period, yet needs testing in January sowing. The husk recovery (%) of Isabgol at Chhindwara condition has shown consistent incremental gains even up to November sowing. Whereas Jabalpur and Gwalior have shown in early October sowing in consistency at Indore condition and other dates of Jabalpur and Gwalior due to climatic variability within season. The swelling factor (ml/ g) has shown exactly similar trend with change in magnitude. Safed musli has shown higher saponin content at Indore than at Gwalior.

Fig-6

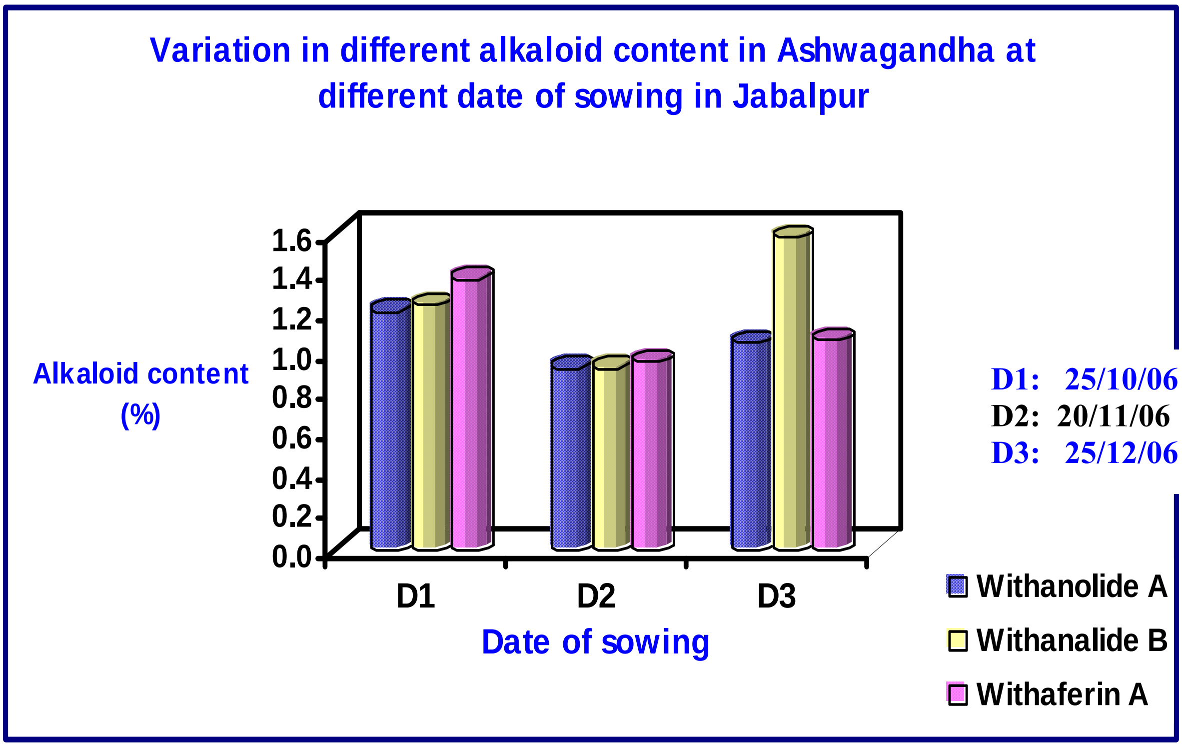

Variation in different alkaloid content in Ashwagandha at different date of sowing in Jabalpur
Alkaloid content (%)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
D1
D2
D3
Date of sowing
D1: 25/10/06
D2: 20/11/06
D3: 25/12/06
Withanolide A
Withanalide B
Withaferin A

Fig-7

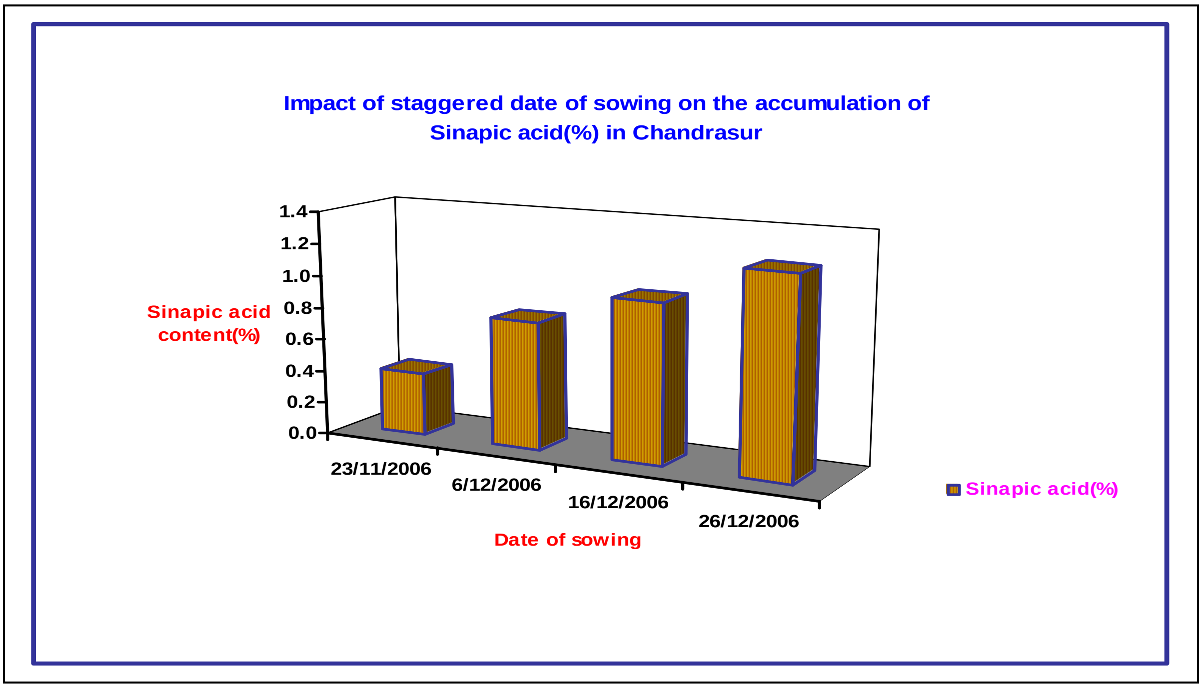
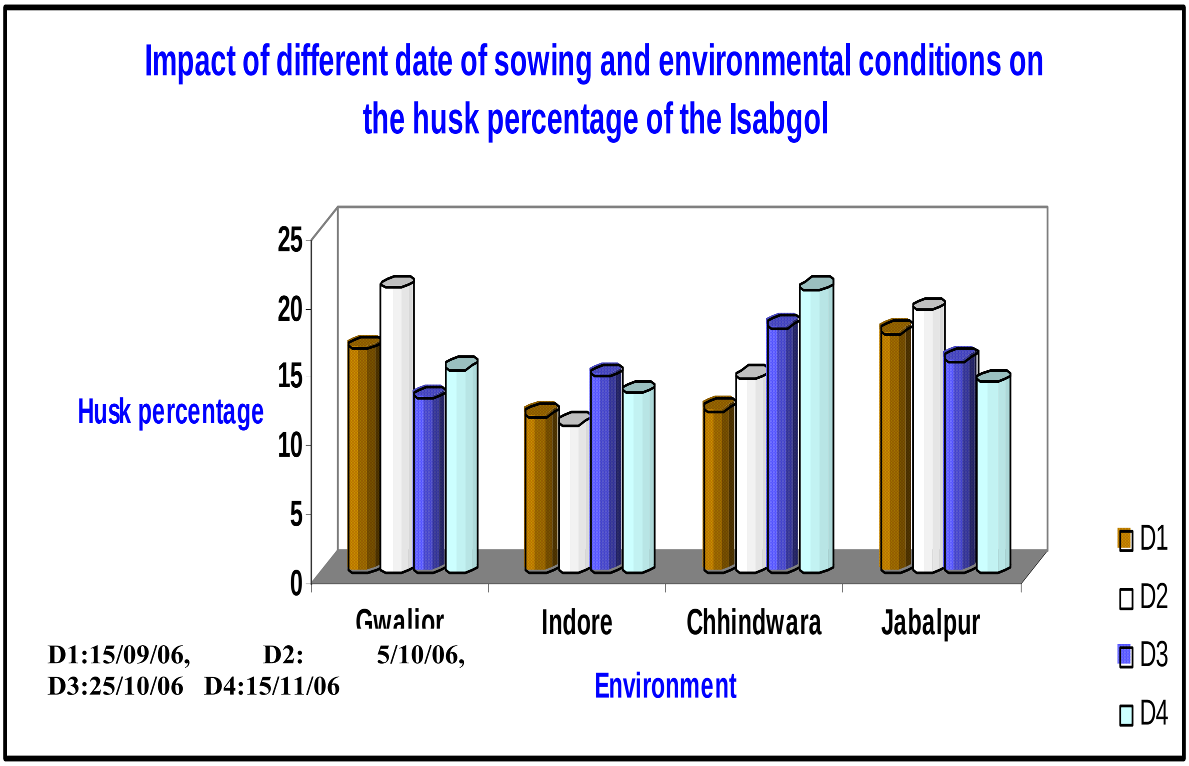
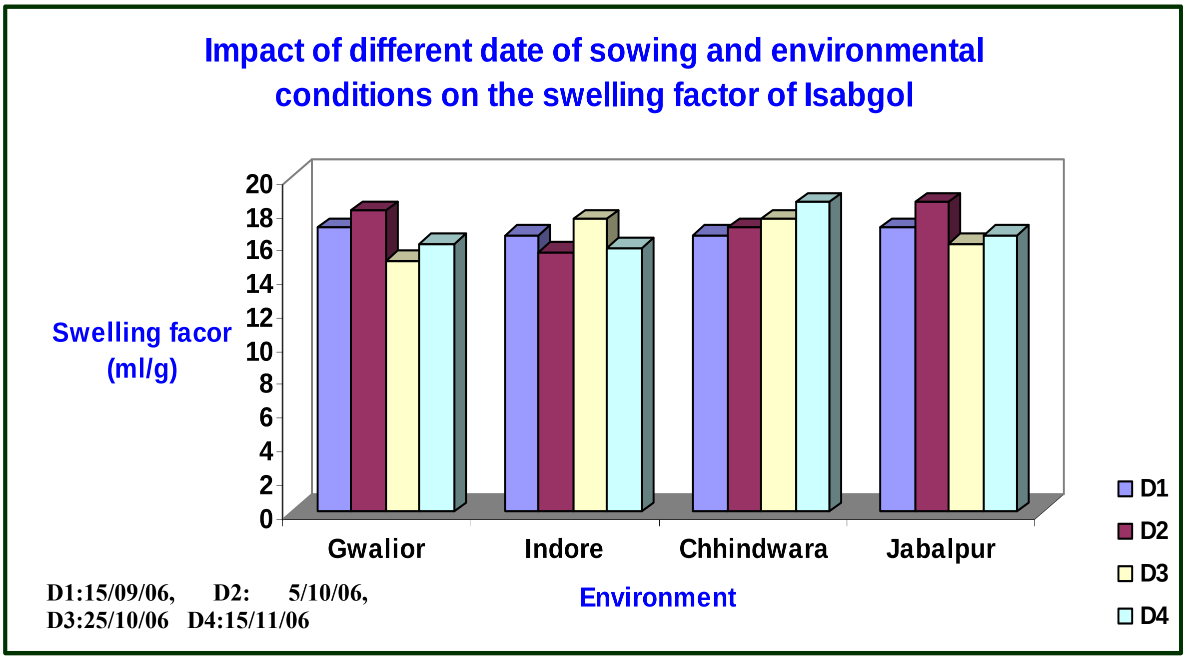

Impact of staggered date of sowing on the accumulation of Sinapic acid(%) in Chandrasur
Sinapic acid content(%)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
23/11/2006
6/12/2006
16/12/2006
26/12/2006
Date of sowing
Sinapic acid(%)

**Fig-8**



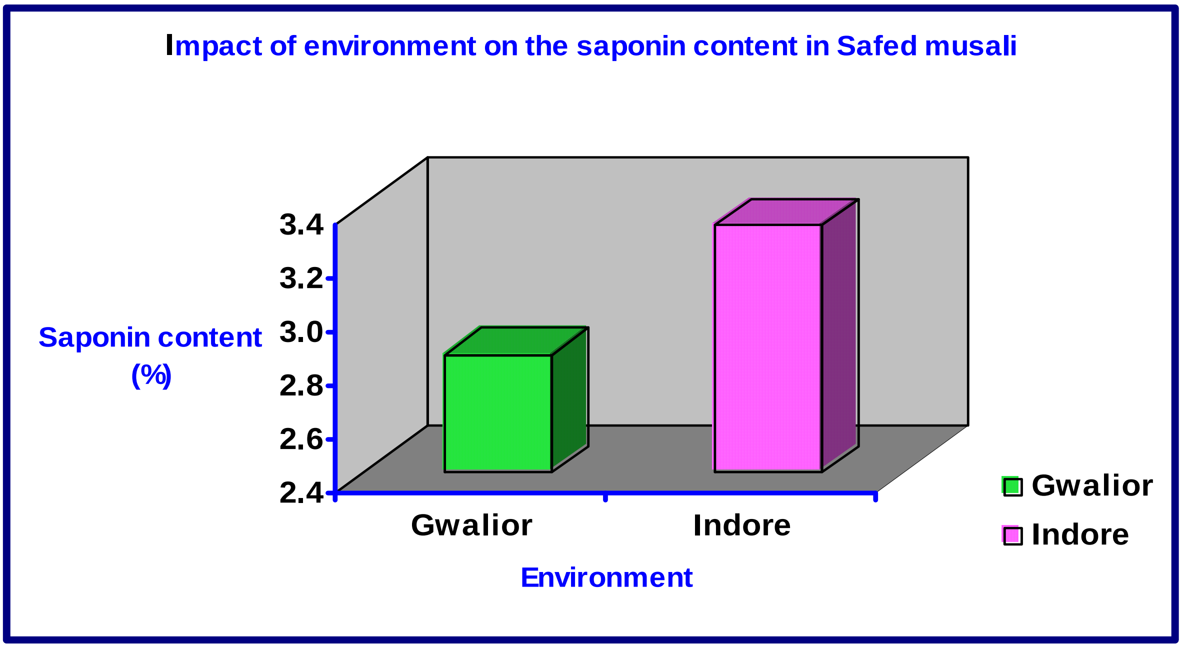
Impact of different date of sowing and environmental conditions on the husk percentage of the Isabgol
Husk percentage
25
20
15
10
5
0
Gwalior
Indore
Chhindwara
Jabalpur
Environment
D1
D2
D3
D4
D1:15/09/06, D2: 5/10/06,
D3:25/10/06 D4:15/11/06


**Fig-9**



Impact of different date of sowing and environmental conditions on the swelling factor of Isabgol
Swelling facor (ml/g)
20
18
16
14
12
10
8
6
4
2
0
Gwalior
Indore
Chhindwara
Jabalpur
Environment
D1
D2
D3
D4
D1:15/09/06, D2: 5/10/06,
D3:25/10/06 D4:15/11/06

**Fig-10**




**Qualitative response of medicinal plants to altitudinal gradient:**
A significant variation in the different quality attributes of some important medicinal plants were observed in response to the altitude gradient of Pachmarhi Biosphere Reserve. It was found that there is a decrease in the fibre content with increase in the altitude which may be attributed to differential impact of temperature on conversion of parenchyma to sclerenchyma. Bottom altitude was found to be better for accumulation of fibre than top altitude in medicinal plants.
**Differential response of medicinal plants to moisture stress:**
Phenology is the calender of events in the life history of plants and indicates the times of seedling appearance, vegetative growth, flowering, fruiting and maturity and seed dispersal of the plants under natural habitat. Study of phenological behavior provides a convincing clue to the relative importance of moisture and temperature in different seasons. Abiotic environments considerably affect the phenology of plants. Present investigation was conducted to assess the impact of moisture stress on the phenological behaviors of three medicinal plants viz., Ashwagandha (*Withania somnifera*), Chandrasur (*Lapidium sativum*) and Isabgol (*Plantago ovata*). Experimental results reflected differential behaviour of flowering and fruiting and bud initiation in these medicinal plants. In Ashwagandha, both flowering and fruiting were significantly affected by moisture stress whereas they remain unaffected in Isabgol. Bud initiation was considerably affected by moisture stress in Ashwagandha and Chandrasur except in Isabgol. Also, fruiting behaviour was significantly affected in Chandrasur. This shows the vulnerable stages of these medicinal plants towards water stress. It was concluded that moisture stress after bud formation is responsible for early fruiting in Chandrasur whereas moisture stress at initial stage may be responsible for early fruiting in Ashwagandha. Similarly, it was revealed that moisture stress after leaf initiation stages have a stimulatory effect on bud initiation.
**Seed germinability in response to different thermal regimes:**
Seed germination phase of plants is considered critical for *in- situ* cultivation of plants as it indirectly determines the crop stand density and consequently the yield of resultant crop. Temperature is an equally important environmental stress under arid, semi-arid and tropical

zone. Hence, impact of high as well as low temperature stresses on potential plant productivity has been a matter of concern. Present investigation throws light on the differential germination and seedling growth behaviour in Ashwagandha, Isabgol and Chandrasur under different temperature stresses. There was a significant rise in the germination percent with rise in temperature from $15^0$C to $35^0$C with maximum value at $35^0$C in all these medicinal plants. Hence, it can be concluded that a rise in the temperature up to $35^0$C has a stimulatory effect on the germination behaviors of these plants. Also, a similar trend was found for germination value and germination energy with their maximum value at $35^0$C in all these medicinal plants. However, a declining trend was observed in the germination energy with the rise in the temperature up to $35^0$C.

# Indian Institute of Horticultural Research, BANGALORE

## Adoption of INFOCROP model for tomato and onion

INFOCROP simulation model, a generic model, developed by Agarwal et al., 2004 was adopted for tomato and onion. To adopt this model for tomato and onion, historic data was collected, analyzed and growth and development was conceptualized. Genetic coefficients were derived either from the field experiments conducted at different agro ecological zones of tomato and onion cultivation or collected from the literature.

In INFOCROP model the total development of the crop is quantified with the help of a development stage (DS), having a value of 0 at transplanting, 1.0 at flowering and 2.0 at maturity in tomato and 0 at sowing, 1.0 at bulb initiation and 2.0 at maturity in onion. The development rate of each stage is controlled by a user specified thermal time, which was collected from the field experiments and literature. The development rate is linearly related to the daily mean temperature above base temperature up to an optimum temperature. Above this optimum temperature the rate decreases until the maximum is reached. If temperature goes below the base or above the maximum the rate of development becomes zero. Water stress and nitrogen stress accelerate flowering, depending upon the severity of stress the rate of development is controlled by increasing canopy temperature.

The dry matter production is calculated by the approach of the radiation use efficiency (RUE). RUE in tomato is 2.5 g/MJ and in onion is 5.5 g/MJ, it is further modified by the development stage, abiotic and biotic factors. Radiation interception by the crop is calculated as a function of LAI, incident solar radiation, radiation captured by the pests and weeds and a crop/cultivar specific extinction coefficient. The growth rate of crop is then calculated as a function of RUE and radiation intercepted by the crop. The net dry matter available each day for crop growth is partitioned in to roots, leaves, stem and storage organs as a crop specific function of development stage based on field experiments. The net growth rate of these organs is then calculated based on the growth rate of the crop, fractions allocated, death due to senescence, and losses due to pests. The weights of these organs are updated everyday based on the initial weights. The net leaf area growth rate is calculated based on initial LAI, leaf area growth rate, death rate of LAI and net loss of LAI due to pests.

The fruits in tomato and bulbs in onion are filled up with a rate based on temperature dependent potential filling rate and the level of dry matter available for growth. The growth of storage organs is terminated when their weight reaches potential weight or no dry matter is available or when the thermal time dependent stage has reached.

The rate of N uptake is dependent upon crop N demand, phonological age, soil N availability, and transpiration, rooting depth and soil water status. A variety specific function GREENF is used to adjust this concentration.

Water stress is determined as the ratio of actual water uptake and potential transpiration. The INFOCROP describes production under water-limited environment by including water balance of soil and water stress effects on phenology and crop growth processes.

## Model calibration and validation

The model was calibrated from the data obtained from field experiments for determinate and indeterminate cultivars in tomato and four important cultivars of onion, grown under potential conditions during 1988-89 at Indian Institute of Horticultural Research, Bangalore.

The initial validation of the model was done with the inputs from experiments conducted at two places. Bangalore and Nasik were selected for onion Bangalore and Hissar for the inputs required. These experiments were conducted during 1988-89.

**Interaction effect of water stress and thrips infestation at different growth stages in onion**

A study was carried out to determine the interaction effect of water stress and the thrips, *Thrips tabaci* infestation on the physiology and yield of onion at different growth stages, cv. Arka Kalyan was planted during January; 2006. Water stress was imposed for 4 weeks at 30, 50, 70 and 90 days after planting for four weeks. One set of plots was sprayed using acephate (1.5g/l) for the control of thrips under both stressed and irrigated conditions at each stage. The other set of plots did not receive insecticide spray. Prior to the first spray ie., 30 DAP first sampling was carried out as a pretreatment count. Further, sampling was made on 7$^{th}$ and 14$^{th}$ day of each spray. During each sampling, 2 plants were randomly collected from each replication in 70% alcohol, filtered and observed for thrips under microscope
Maximum day temperature varied from 28.0 to 33.65$^{o}$C and night temperature varied from 14.5 to 21.1$^{o}$C. Stomatal conductance ($g_{s)}$ (0.253cm/s$^{1}$) and photosynthetic rate (2.38mmoles/m$^{2}$/s$^{1}$) was higher in water stressed and sprayed Plants at 30DAP.In unsprayed and water stressed plants it was 0.127cm/s$^{1}$and 0.93mmoles/m$^{2}$/s$^{1}$. At 50,70 days stress also stomatal conductance was higher in sprayed and stressed plants. Transpiration was also higher in sprayed and stressed plants. A yield reduction of 24, and 20% was observed in unsprayed and stressed plants at 30 and 50DAP compared to unsprayed plants. About 11% yield reduction was observed in unsprayed and stressed plants at 70DAP.At 90 DAP differences in yield between treatments were non significant.
Statistical analysis were carried out to study the interaction of biotic and abiotic factors on the physiology and yield of onion crop (A. Kalyan) individually for four treatments viz.,
$T_1$: irrigated (control) with spray;
$T_2$: irrigated (control) without spray;
$T_3$: stress with spray and
$T_4$: stress without spray.

Salient results are presented as below:

A) In the case of control with spray plots, correlation analysis showed that onion yield is significantly positively correlated with $g_s$ (r=0.73) ($p<0.05$). Further, about 93.5 % of the variability in yield could be collectively explained by both biotic and abiotic factors. Out of which, gs and thrips count accounted for 61.6 % of yield variability (Y = 10587.76 +4932.28 $g_s$ - 277.89 thrips count).
B) In the case of control without spray plots, individual correlation analysis does not reveal any significant correlated variable with crop yield, model developed indicated that about 83.9% of the variability in onion crop yield could be collectively explained by both biotic and abiotic factors.
C) In the case of stress with spray, correlation analysis showed that onion yield is negatively related with Tn (r=-0.863), $g_s$ (r=-0.861) ($p<0.05$). Further, about 90.1% of the variability in crop yield could be collectively explained by both biotic and abiotic factors. Out of which, $g_s$, Tn and

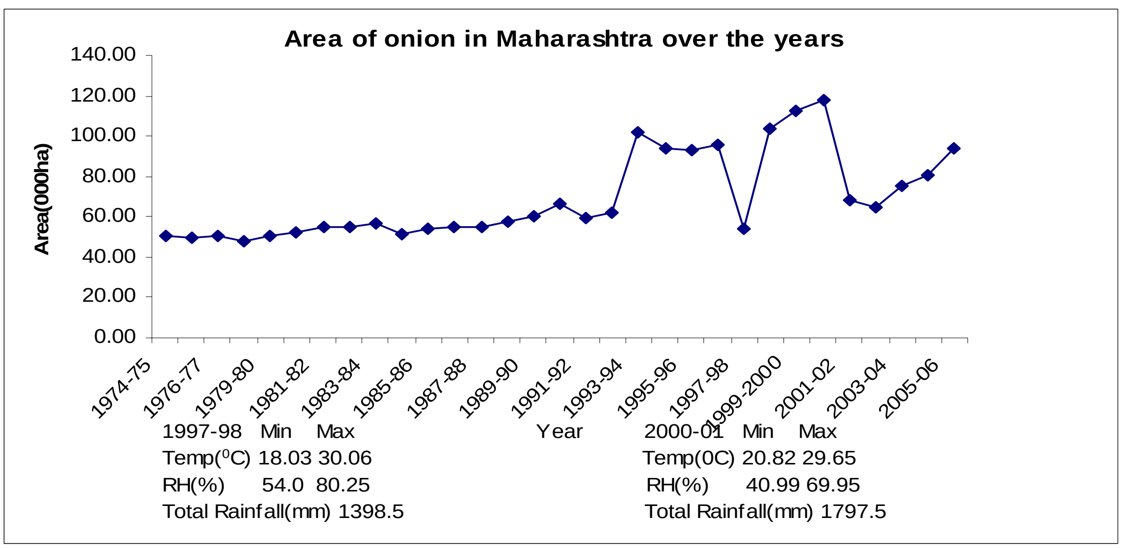
thrips count accounted for 77.7 % of yield variability ($Y = 11734.6 - 18043.6\ g_s - 568.17\ T_n - 66.08$ thrips count).

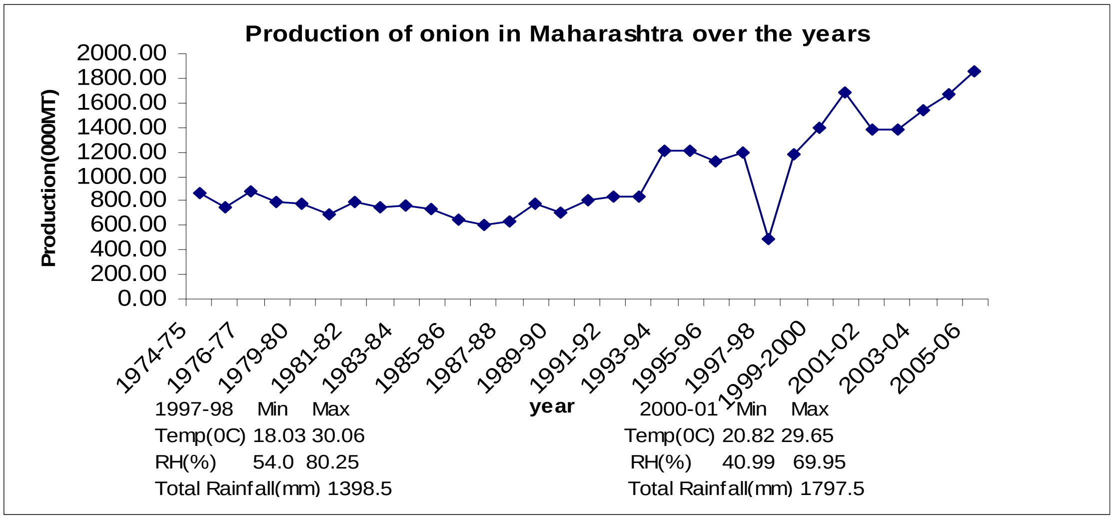
D) In the case of stress without spray Correlation analysis showed that onion yield is related to biomass, Transpiration rate ($T_n$) (r= -0.95), stomatal conductance ($g_s$) (r=-0.92) and Thrips (r=-0.79) ($p<0.05$). Also, Thrips count is positively correlated with Tn (r=0.81) and $g_s$ (r=0.84). Further, about 94.5% of the variability in onion yield could be collectively explained by both biotic and abiotic factors. Out of which Tn and thrips count is contributing 90% solely, as explained by the model ($Y = 12176.14 - 12220.99\ T_n - 132.78$ thrips count).

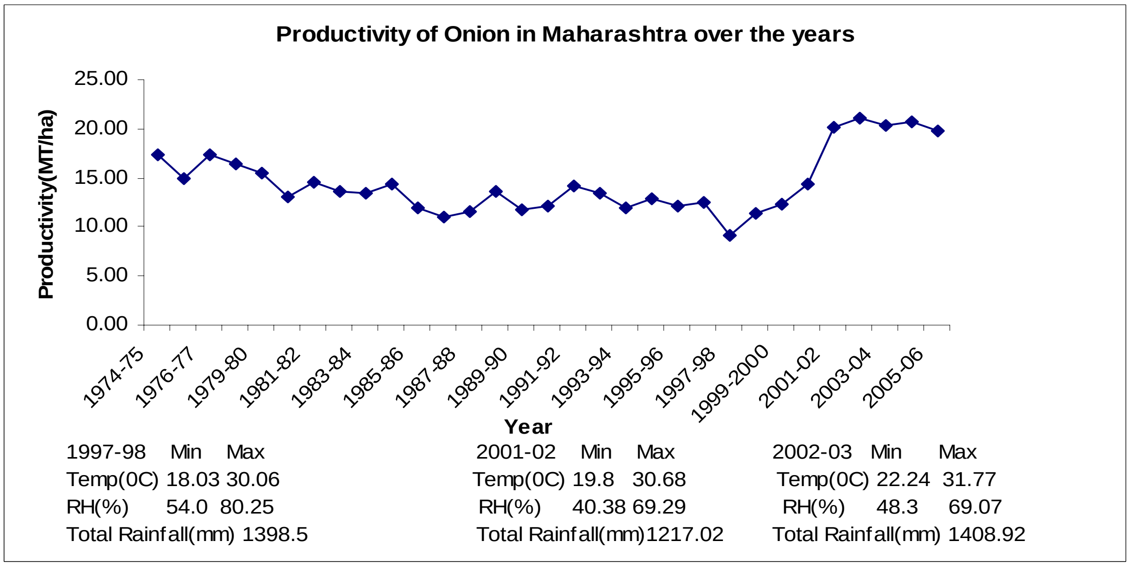
**Trend analysis for onion productivity in relation to weather parameters**

Area and production of onion crop in Maharashtra decreased in 1997-98 (53.8'000 ha and 491.0 MT) and gradually increased and attained peak in the 2000-01(118.1'000 ha and 1687.5 MT). In 1997-98 minimum and maximum temperatures were 18.03 and 30.06 $^0$C respectively and the total rainfall (of both Lasalgaon and Sinnar) was less (1398.5 mm) compared to 2000-01(1797.5 mm). Where as in the year 2000-01 minimum and maximum temperature recorded 20.82 and 29.65 $^0$C respectively. Relative humidity both minimum and maximum was found less in the year 1997-98 compared to 2000-01.

Productivity of onion showed fluctuation over the years and gradually decreased in 1997-98(9.13 MT/ha) and increased in 2001-02(20.18 MT/ha) and attained maximum value in 2002-03(21.15 MT/ha). Environmental condition particularly temperature both minimum and maximum was high and relative humidity recorded was low in the year 2002-03 than in 1997-98. Total rainfall of Maharashtra (including Lasalgaon and Sinnar) was maximum (1408.92 mm) in 2002-03 than in 1997-98 and 2001-02.






## Survey of grape growing areas

In order to assess the phenology of grapes in relation to growing degree days for different grape growing areas of Maharashtra and Karnataka the survey was taken up during the year 2006-07. The information on time of fore pruning and days taken for different phonological stages of grapes was collected from Nasik, Pune, Sangli, Solapur, Bijapur and Bangalore.

For cv. Thompson Seedless and its clones, fore pruning (pruning for crop) is taken up from September 1$^{st}$ week till November 3$^{rd}$ week in Solapur, Pune, Sangli and Bijapur areas and in Nasik region pruning is taken up from September 1$^{st}$ week till November 2$^{nd}$ week. Where as in Bangalore area the pruning is taken up from October 1$^{st}$ week till November 2$^{nd}$ week. For colour grapes, cv. Sharad Seedless and Flame Seedless, pruning is taken up from September 1$^{st}$ week till October 10$^{th}$ in all these areas, if taken up later the post veraison colour development coincides with the higher temperature periods leading to impaired colour development. In case of wine varieties the pruning is taken up from 2$^{nd}$ week of September till 2$^{nd}$ week of October in Nasik, Pune, Sangli and Bijapur areas. Whereas in Bangalore the pruning is taken up from October 2nd week till November 1st week. A wide period of pruning is followed in these grape growing areas to supply fruits for domestic and export markets in case of table grapes, cv. Thompson Seedless and its clones and cvs. Sharad Seedless and Flame Seedless. The period of pruning is determined by the availability of dry weather immediately after the monsoon season and congenial temperature conditions for fruit development. Hence, there is a fixed period for taking up fore pruning, more so important in case of colour table grapes and wine varieties. In case of wine varieties fruit quality and subsequently wine quality are affected by temperature. Cool climates favor lower sugar and higher acid development, whereas higher temperatures favor the opposite. Generally, longer growing seasons with moderate temperatures are required for wine cultivars for development of characteristic aroma, flavour, sugars, acid and skin colour. Hence, the increase in temperature will meet the requirement of growing degree days early for grapes leading to early maturation. This can be managed by following mitigation strategy of preponing the pruning time in the context of climate change scenario.

**Table1**. The summation of growing degree days available for vine growth at different grape growing areas;

| Areas | Growing degree days From Sept-March |
|---|---|
| Bangalore | 2650-2800 |
| Bijapur | 2900-3200 |
| Nasik | 2600-2750 |
| Pune | 2700-3000 |
| Sangli | 3200-3400 |
| Solapur | 3200-3400 |

**Table 2a**. Days taken for different phenological stages in cv. Thompson Seedless grapes growing areas of Maharashtra and Karnataka under different pruning dates.

| | Bijapur | | Solapur | | Sangli | |
|---|---|---|---|---|---|---|
| Phenological stage | Sept 1week Oct 2nd week | Oct3rd week Nov3rd week | Sept 1week Oct 2nd week | Oct3rd week Nov3rd week | Sept 1week Oct2nd week | Oct3rd week Nov 3rd week |
| Bud burst | 10-14 | 12-15 | 10 | 12-15 | 11-12 | 12-14 |
| Flowering | 35-40 | 35-45 | 30-45 | 40-50 | 35-40 | 35-40 |
| Verasion | 70-90 | 90-95 | 75-80 | 90-100 | 70-80 | 70-80 |
| Fruit Maturity | 130-150 | 140-155 | 120-145 | 140-150 | 135 | 135-40 |

**2b.**

| | Pune | | Nasik | | Bangalore | |
|---|---|---|---|---|---|---|
| Phenological stage | Sept 1week Oct 2nd week | Oct3rd week Nov 3rd week | Sept 1week Oct 2nd week | Oct3rd week Nov2nd week | Oct 1st week Oct2nd week | Oct3rd week Nov1nd week |
| Bud burst | 10-12 | 12-15 | 10-12 | 15 | 10-15 | 10-15 |
| Flowering | 35-45 | 35-45 | 35-45 | 45-55 | 35-45 | 40-45 |
| Verasion | 70-90 | 90-100 | 80-90 | 85-90 | 80-85 | 80-90 |
| Fruit Maturity | 130-145 | 145-150 | 140-150 | 150-160 | 135-145 | 145-150 |

**Table3.** Days taken for different phenological stages in colour table grapes (cv. Sharad Seedless and Flame Seedless) growing areas of Maharashtra and Karnataka

| | Bijapur | Pune | Solapur | Nasik |
|---|---|---|---|---|
| Phenological stage | Sept 1week | Sept 1week Oct 2nd week | Sept 1week Oct 2nd week | Sept 1week Oct2nd week |
| Bud burst | 10 | 12 | 8-10 | 11-12 |
| Flowering | 30 | 35 | 35 | 35-40 |
| Verasion | 75 | 70 | 75-80 | 75-85 |
| Fruit Maturity | 110-120 | 90-110 | 100-110 | 110-125 |

**Performance of tomato hybrid under rain shelter with rain simulation and comparison with open field crop (Jan-April 2006)**

Tomato hybrid Allround was transplanted on 15th Dec 2005 in open and under rain shelter to study its performance with different levels of rain simulation using overhead micro sprinklers. The crop was given normal irrigation through drip for all the treatments @ 0.7 Epan replenishment. There were 5 treatments replicated 4 times with 30 plants per treatment. Plant spacing adopted was 1.0 X 0.5 m equivalent to 20,000 plants per ha. The crop was supplied with FYM @ 25 t/ha and NPK @ 200 kg each per hectare. Necessary plant protection measures were taken using chemical pesticides except for the fruit borer management, which was done by spraying NPV at 28, 35 and 42 days after transplanting. In general the crop growth was excellent under rain shelter in comparison to open field grown crop and under rain shelter towards the later crop growth period *Alternaria leaf* spot incidence was quite high especially with higher levels of sprinkler water given to simulate rains. The results showed that crop growth, yield and yield components under rain shelter were significantly superior irrespective of the treatments as compared to open field grown crop. The yield was almost double in most of the treatments. The main reason for low yield in open was due to significantly lower fruit size and to some extent due to reduced number of fruits per plant. Under rain shelter all treatments receiving over head sprinkler water performed better than only drip irrigated crop indicating that change in micro climate through reduced temperature and increased humidity favored better crop growth and yield components. Among different levels of sprinkler watering the treatment which received 50 % performed best with highest fruit yield of 132 t/ha with higher mean fruit weight of 87.3 g. Further enhancing sprinkling reduced yields by way of reduced fruits per plant which might be due to excess water reduced fruit set and indirectly affected by higher alternarial laef spot incidence, which reduced photosynthesizing area of the lamina. Thus the results indicate that maintaining optimal microclimate favours better crop growth, yield components as well as yield.

**Table 4.**Performance of tomato cultivars in open and under rain shelter during summer season

| **Treatments** | **Plant ht. (cm)** | **LAI at 80DAT** | **Leaf dry matter content (% )** | **No.fruits/ plant** | **Mean fruit wt. (g)** | **Yield (t/ha)** |
|---|---|---|---|---|---|---|
| T1 - 25 % through sprinklers | 92.3 | 2.96 | 6.23 | 79.3 | 80.1 | 127.0 |
| T2 – 50 % through sprinklers | 100.0 | 3.32 | 7.05 | 75.7 | 87.3 | 132.2 |
| T3 - 75 % through sprinklers | 90.0 | 4.18 | 8.33 | 69.0 | 88.1 | 121.6 |
| T4 – Through drip | 88.3 | 2.88 | 6.05 | 76.7 | 73.0 | 111.9 |
| T5- Open field | 76.0 | 2.62 | 8.62 | 66.2 | 48.1 | 63.7 |
| CD at 5% | 8.21 | 1.61 | 1.36 | 3.26 | 8.31 | 5.44 |

**Table 5.** Performance of tomato cultivars in open and under rain shelter during Kharif season

| **Treatments** | | **Plant ht. (cm)** | **No. of flower clusters** | **No.fruits/ plant** | **Mean fruit wt. (g)** | **Yield (t/ha)** |
|---|---|---|---|---|---|---|
| JK | Rainshelter | 92 | 22 | 79 | 47 | 74.27 |
| | Open | 77 | 12 | 59 | 40 | 47.29 |
| Arka Ananya | Rainshelter | 95 | 26 | 72 | 66 | 95.84 |
| | Open | 83 | 21 | 52 | 58 | 68.32 |
| Abhinava | Rainshelter | 109 | 18 | 72 | 59 | 84.96 |
| | Open | 94 | 18 | 44 | 59 | 51.92 |
| All Rounder | Rainshelter | 89 | 16 | 59 | 66 | 77.89 |
| | Open | 77 | 14 | 44 | 57 | 58.16 |
| CD at 5% | | 10.6 | 4.36 | 4.36 | 3.38 | 4.41 |

The results of a field trial conducted to study the performance of different tomato cultivars in open and under rainshelter during the monsoon season has revealed that the marketable tomato fruit yield was 48 per cent higher under rain shelter as compared to open. This higher yield was due to better plant growth, less incidence of early blight, a predominant yield reducing factor during the rainy season, better yield components such as higher number of fruits per plant and better mean fruit weight. The trend was same in all the leading tomato cultivars tested and the best performance was with Arka Ananya followed by Abhinava.

**f) Validation of Thermal day degrees for aphids and thrips on Rose under field conditions**

As insects are poikilothermic *i.e.*, their rate of development will be depending on the surrounding temperatures. Developmental time will be effected with the temperatures in the surrounding environments. For this purpose thermal day degrees i.e., total day degrees accumulated required for the complete development of two pests on rose i.e., thrips, *Scirtothrips dorsalis* and aphids, *Macrosiphum rosae* was validated under field conditions. The present observations were done on rose cv. Gladiator grown under field conditions.

**Thrips, *Scirtothrips dorsalis***

Thermal day degrees requirement for the thrips on rose under field condition was found to be 264.65 $^{o}$C during 4-26$^{th}$ February 2007 (Table 6**)**. For thrips, temperature thresholds (9.7$^{o}$C) for the development of the pest have been followed as per the studies of Tatara (1994). Thrips have completed the development in 23 days during February.

**Aphids, *Macrosiphum rosae***

**Table 6:**Field validation of the requirement of thermal day degrees requirement was done for this pest in September 2006 and again during January 2007.

| Sl.No. | Pest | Period of observation | Thermal day degrees requirement |
|---|---|---|---|
| 1. | Thrips, *Scirtothrips dorsalis* | 4-26$^{th}$ February 2007 | 264.65 |
| 2. | Aphdis, *Macrosiphum rosae* | 9-28 September 2006 | 125.23 |
| 3. | -do- | 1-11 January 2007 | 118.91 |

This information can be used for different changing climate situations in future for the occurrence of pests, no. of generation *etc*.. There could be a possibility of little early development of the pest and chances of accommodating 1 or 2 more generations in a year and thereby causing additional damage to the crop.

Multiple regressions studies: During 2006-2007 multiple regression analysis was carried out with weather parameters and pest numbers for developing prediction models for thrips and aphids on rose. The prediction equations by including significantly correlated weather parameters and pest numbers are presented below (Table 7**)**.

**Thrips,** *Scirtothrips dorsalis*

**Table7: Number of thrips/bud vs. weather parameters in rose**

| **Variety** | **Regression model** | **Regression equation** | **Regression co-efficient ($R^2$)** |
|---|---|---|---|
| Gladiator | Linear | $Y = - 45.33 + 1.05 (x_1) + 0.865 (x_2) + 0.124 (x_3) - 0.199 (x_4) - 0.149 (x_5) + 3.205 (x_6) + 0.78 (x_7)$ | 0.755 |

Where, Y= thrips no./bud; $x_{1;}$ Maximum temperature, $x_{2;}$ Min. Temp. $x_3$ = Max. RH, $x_4$= Min. RH $x_5$ = wind speed $x_6$= evaporation and $x_7$ = rainfall.

$R^2$ value of 75.5 per cent revealed that 75.5 % variability of thrips population could be explained due the weather parameters viz., Max. temperature, Min. temperature, Max. and Min. relative humidity, wind speed, evaporation and rainfall together in rose cultivar, Gladiator.

**Aphids,** *Macrosiphum rosae*

**Table 8.** Number of aphdis/10 cm stalk of rose vs. weather parameters in rose

| **Variety** | **Regression model** | **Regression equation** | **Regression co-efficient ($R^2$)** |
|---|---|---|---|
| Gladiator | Linear | $Y = - 30.79 + 1.21 (x_1) - 3.87 (x_2) + 0.475 (x_3) + 0.179 (x_4) - 0.234 (x_5) + 6.117 (x_6) + 1.19 (x_7)$ | 0.788 |

Where, $x_{1;}$ Maximum temperature, $x_{2;}$ Min. Temp. $x_3$ = Max. RH, $x_4$= Min. RH $x_5$ = wind speed $x_6$= evaporation and $x_7$ = rainfall.

$R^2$ value of 0.788 revealed that 78.8 % variability of aphids population could be explained due the weather parameters *viz*., Max. temperature, Min. temperature, Max. and Min. relative humidity, wind speed, evaporation and rainfall together in rose cultivar, Gladiator.

**g) Seasonal incidence of thrips in onion:**

During the year 2006-07, three crops of rose onion were raised and the incidence of onion thrips was recorded on different dates. Onion variety Arka Kalyan was planted in plots of 3 m x 3 m on 2-8-06, 2-11-06 and 2-1-07. Incidence of thrips was recorded in 20 plants by carefully examining the plants at different intervals. Total of 24 observations were taken and the data is provided in Table 9. It was found that the incidence of thrips was low (max of 8/plant) during the study period between August and January. However, the incidence increased by the end of February to 11.65 per plant.

**Table 9.** Incidence of thrips in onion on different dates during 2006-07 at Bangalore**.**

| Date | Thrips/pl | Max temp ($^0$C) | Min temp ($^0$C) | Rainfall (mm) | RH in Morning (%) | RH in evening (%) | Evaporation (mm) | Wind speed (km/h) |
|---|---|---|---|---|---|---|---|---|
| 21.8.06 | 1.80 | 28.58 | 20.42 | 42.40 | 82.86 | 72.71 | 9.28 | 3.36 |
| 23.8.06 | 2.45 | 28.36 | 20.36 | 50.60 | 83.29 | 74.57 | 7.52 | 3.57 |
| 28.8.06 | 3.35 | 28.43 | 19.07 | 14.00 | 79.00 | 68.71 | 5.71 | 4.21 |
| 4.9.06 | 8.60 | 29.29 | 20.00 | 3.90 | 78.14 | 69.29 | 6.54 | 4.70 |
| 14.9.06 | 8.00 | 29.71 | 20.79 | 1.00 | 80.57 | 65.86 | 6.65 | 3.57 |
| 23.9.06 | 9.00 | 28.50 | 19.29 | 0.00 | 75.71 | 63.29 | 10.90 | 4.50 |
| 3.10.06 | 2.60 | 29.07 | 19.93 | 9.80 | 79.86 | 64.86 | 6.99 | 4.51 |
| 13.10.06 | 0.60 | 29.00 | 18.93 | 31.70 | 84.00 | 67.29 | 3.91 | 3.67 |
| 23.10.06 | 2.60 | 29.29 | 18.43 | 6.90 | 78.14 | 67.86 | 5.73 | 3.86 |
| 6.11.06 | 1.30 | 27.79 | 19.57 | 51.90 | 85.71 | 69.71 | 4.76 | 2.81 |
| 13.11.06 | 1.50 | 26.36 | 18.64 | 65.10 | 82.86 | 72.29 | 4.10 | 2.14 |
| 20.11.06 | 0.30 | 26.29 | 18.57 | 21.90 | 85.43 | 78.57 | 6.29 | 2.57 |
| 30.11.06 | 0.50 | 28.50 | 16.57 | 0.00 | 83.43 | 69.00 | 4.45 | 3.29 |
| 10.12.06 | 0.50 | 26.86 | 13.71 | 0.00 | 82.71 | 73.57 | 5.57 | 3.71 |
| 20.12.06 | 1.50 | 27.57 | 16.07 | 0.00 | 76.00 | 64.50 | 5.41 | 4.64 |
| 27.12.06 | 0.70 | 25.21 | 16.29 | 0.00 | 79.00 | 68.43 | 5.72 | 3.29 |
| 3.1.07 | 1.50 | 26.84 | 14.36 | 0.00 | 79.71 | 69.99 | 5.25 | 3.71 |
| 10.1.07 | 2.90 | 27.79 | 12.36 | 0.00 | 76.71 | 70.00 | 5.38 | 4.14 |
| 17.1.07 | 5.60 | 28.50 | 12.43 | 0.00 | 80.86 | 74.00 | 4.60 | 4.14 |
| 24.1.07 | 5.75 | 29.57 | 10.14 | 0.00 | 81.00 | 71.29 | 4.82 | 4.79 |
| 31.1.07 | 3.20 | 28.57 | 13.93 | 0.00 | 78.86 | 69.86 | 7.77 | 5.21 |
| 7.2.07 | 1.95 | 29.86 | 10.07 | 0.00 | 74.29 | 71.71 | 4.50 | 5.50 |
| 14.2.07 | 5.15 | 30.00 | 13.57 | 0.00 | 61.00 | 36.14 | 5.65 | 5.50 |
| 24.2.07 | 11.65 | 29.29 | 14.57 | 0.00 | 55.00 | 38.14 | 4.06 | 5.00 |

**Correlation between thrips incidence and weather parameters:**

The incidence was correlated with weather parameters that prevailed during the preceding week, i.e., average maximum temperature, average minimum temperature, total rainfall, average RH in morning, average RH in evening, and wind speed (km/h) and average evaporation (mm). The correlations of thrips incidence with different weather parameters are given in Table 10. It was found that the incidence of thrips was significantly and positively correlated with average maximum temperature and evaporation. However, it was negatively correlated with the relative humidity in the afternoon. The correlation with minmum temperature and rainfall was not significant.

**Table 10.** Correlation of thrips incidence with different weather parameters

| Weather Parameter | Correlation |
|---|---|
| Max temperature $^0$C | 0.53968* |
| Min temperature $^0$C | -0.01805 |
| Total Rainfall (mm) | -0.35205 |
| RH in morning | -0.6153* |
| RH in afternoon | -0.54531* |
| W speed | 0.215142 |
| Evaporation | 0.496232* |

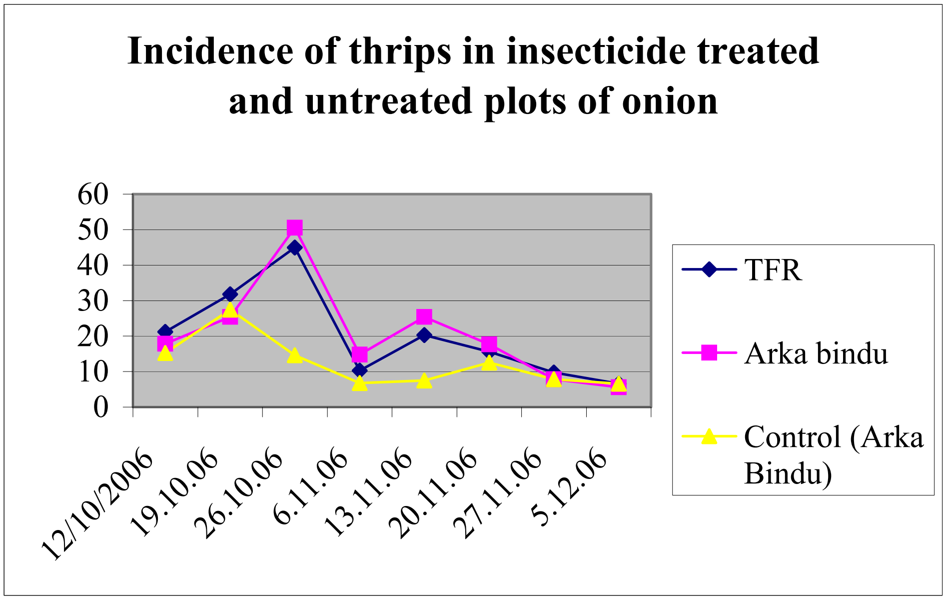
* Significant correlation at (P=0.05)

**Comparison of the incidence of thrips in insecticide sprayed and no sprayed plots:**
A study was made on the incidence of thrips in onion following regular insecticide treatments as compared to no insecticide treated plots (fig 5). The onion variety TFR and Arka Bindu and was sown on 10-9-06 in a plot of 25 x 50 m. In these plots, five sprays of insecticides were given (dimethoate, dimethoate, lamdacyhalothrin, imidacloprid and dimethoate) once in 7 days interval to control thrips starting from 12-10-06. In another plot variety Aeka Bindu was taken without any spray. Observation on thrips incidence was recorded in 20 plants in each plot on 19-10-06, 26-10-06, 3-11-06, 6-11-06, 13-11-06, 20-11-06, 27-11-06 and 5-12-06. The data given in Table 11 shows a comparison of the thrips incidence in sprayed plots and in the plot where no insecticide applications were made, clearly indicates that thrips incidence did not increase unreasonably high in the unsprayed plot. In view of the above findings, insecticide applications may play a very important role in unusual increase in pest population in addition to the climate factor.

**Table 11. Incidence of thrips in insecticide sprayed and non-sprayed plots:**

| Date of observation | Variety | | |
|---|---|---|---|
| | TFR | Arka Bindu | Control (unsprayed Arka Bindu) |
| 12-10-06 | 21.2 | 17.8 | 15.2 |
| 19.10.06 | 31.8 | 25.4 | 27.5 |
| 26.10.06 | 44.95 | 50.5 | 14.6 |
| 3.11.06 | 20.7 | 21.2 | 12.5 |
| 6.11.06 | 10.3 | 14.75 | 6.8 |
| 13.11.06 | 20.3 | 25.4 | 7.5 |
| 20.11.06 | 15.6 | 17.7 | 12.5 |
| 27.11.06 | 9.7 | 7.8 | 7.8 |
| 5-12-06 | 6.6 | 5.6 | 6.6 |

**Fig5**: Incidence of thrips in insecticide treated and untreated plots of onion**.**



# CSK HP Agricultural University, Palampur

**Impact of Climate Change on Apple –shift in recent years**

The shift of apple belt upward due to decreasing chilling hour's requirements of the crop has been observed in apple growing areas of Himachal Pradesh. The new areas of apple cultivation have appeared in Lahaul and Spitti and upper reaches of Kinnaur district of Himachal Pradesh, as evident from the farmers' survey carried out in the regions and the analysis of secondary data. The minimum temperature during winter season is important for meeting the chilling requirements of apple crop. In general temperature below $7^0$C for total 800-1400 hours is taken as chilling requirement of apple, however temperature below $1^0$C and above $18^0$C is not desired for chill units accumulation.

The Cumulative chill units' requirements of apple for Kullu (Bajaura) and Shimla (Theog) regions were calculated using two different models. The Model given by Ashcroft *et. al.* (1997) uses only average temperature of coldest months whereas, the Utah model uses daily maximum and minimum temperature. The data on cumulative chill units of coldest months showed decline of more than 9.1 units per year in last 23 years. The reduction was more during November and February months. Average decrease of 11.9 chill units per year was observed at Bajaura during November to February.

The Utah model also showed decrease of more than 17.4 chill units every year due to increase in surface air temperature at Bajaura. Data on chill units for Bajaura and Theog region have presented in graph (Appendix I). The meteorological data recorded at apple growing region Bajaura showed increasing temperature trends during November to March months. Past 18 years data base showed that mean temperature is decreasing at the rate of $0.09^0$C to $2.1^0$C per year from November to April whereas maximum temperature showed an increasing trend of $5.8^0$C to $8.1^0$C during November to April. The minimum temperature during November to April varied from 3.6 $^0$C to 9.0 $^0$C whereas maximum temperature varied from $22.9^0$C to $26.3^0$C. The increase in maximum temperature reduces the total chilling hours in the region which resulted in the shift of apple belt upwards towards cooler areas. The trend analysis of rainfall for past 41 years recorded at Katrain (Kullu valley) showed 77.0 mm increase of rainfall during November to May. However during winter months January alone showed decrease in rainfall. The increase in rainfall and decrease snow fall during winter months consequently reflected in the low chilling hours in the regions.

Similarly, in another apple growing region of Himachal Pradesh Theog (Shimla district) also showed similar trend of shifting apple belt towards upper areas. The data also exhibited the same situation in the decrease of chill units. The decrease was 19.0 cumulative chill units' hours per year at Theog region. The temperature trends in corresponding period showed increase in minimum and maximum temperature by $1.6^0$C and $1.3^0$C in last 12 years at Theog region.

The minimum temperature during winter months i.e. November to April varied from $8.0^0$C to $11.9^0$C. The minimum temperature below $7^0$C is experienced only during December to February. Maximum temperature varied from $12.2^0$C to $28.1^0$ C during November to March.

The mean temperature rate per year from November to March showed increasing trend varying from $0.14^0$C to $0.20^0$C annually. Similar increase was also observed in Maximum temperature during the same period. Thus increasing maximum temperature during winter months reflected in the reduction of chilling hours for apple in the region. Rainfall during winter months from November to February showed a decreasing trend.

Trend analysis of snowfall data indicated that total snow fall showed decreasing trends at the rate 82.7 mm annually in the entire Satluj river basin. The annual average snow fall over 21 gauging sites located in Satluj basin from 2000masl to 4000masl for last 22 years also showed decrease in snowfall at the rate of 1.6 mm per year. This is the major reason of reduction of chilling hours for apple in the region.

The apple shift is also evident from the decrease of total area under apple in the state. In recent years, the total area under apple in the entire state have fallen from 92,820 ha in 2001-02 to 86,202 ha in 2004-05 whereas, area in Lahaul & Spitti and Kinnaur district which lie above 2500 masl showed increase every year in last ten years.

The farmers perception were also summarized for these apple growing region using farmers survey which revealed that per farmer area under apple showed decrease in Kullu and Theog valley by 18.2 and 3.3 percent respectively. The area in higher elevation (above 2500 masl) namely Lahual and Spitti valley showed substantial increase by more than 127 percent over the decade.

The area under apple in Kinnaur district increased from 5516 hectare to 7720 hectare and in Lahaul and Spitti from 334 hectare to 554 hectare in last ten years.

**Impact of climate change on crop performance**

Climatic parameters of Himachal Pradesh revealed increasing trends of mean annual temperature in all the elevation zones of Himachal Pradesh. The magnitude of increase of temperature is more at higher altitude than plain area. The impact of increasing temperature on crop performance with regard to reproductive and maturity phase were studied for both rabi and kharif season crops.

**Rabi crops**

The reproductive phase (days to flowering) and maturity phase shortened by five and fifteen days in early sown and late sown wheat crop observed at Palm valley of Himachal Pradesh. The maturity phase was observed to be extended by four days but reproductive phase shortened by nineteen days in last fifteen years in early sown crop. The corresponding crop period indicated 2 to 3 $^{0}$C in maximum and 1.0 $^{0}$C in minimum temperature rise in last 3 decade data in the region. Similarly, linseed crop which is sown during the period between October 10 to November 10, in the region also indicated decrease in days to reproductive and maturity phase in all the varieties. The data on reproductive and maturity phase of the barley crop was observed at Bajaura in Kullu Valley. The crop is sown in *rabi* season during October month.

Both reproductive and maturity phases' period enhanced by ten to twenty six days in the region. The corresponding crop period showed decrease in temperature by 2.0$^{0}$ C in maximum and slight increase in minimum temperature by 0.4$^{0}$C in last twenty three years data.

**Kharif crop**

The kharif season crops at Palampur behaved differently. The soybean crop which was sown during 10$^{th}$ to 22$^{nd}$ June showed increase in number of days to attain flowering and maturity phases at Palampur. The corresponding temperature during crop period was observed to be risen by 1.0 $^{o}$C in maximum and 0.2$^{O}$C in minimum. The June months in last 30 years data indicated decrease of 0.8 $^{O}$C in last three decade which could have delayed the crop maturity and flowering in soybean

Rice crop behaved differently at Palampur compared to soybean. Rice was transplanted during July 10 to July 30, 2007 in last 20 years. Days to flowering in two varieties (Himdhan-1 and K-39) were analyzed and data showed one to ten days shortening of reproductive phase in Palampur region. The corresponding maximum temperature rise during the crop period was 1.0 $^{0}$C where as minimum temperature showed slight decrease of 0.2$^{0}$C.

Maize crop was sown during June 10 to 25 in last 20 years at Bajaura. Medium maturing varieties showed shortening of maturity phase by one to four 4 days and enhancement of 505 silking stage phases by two to six days. The maturity phase in early maturing variety was increased by eight days at Bajaura. The temperature trends in corresponding crop period showed decrease in maximum and minimum temperature by 0.6 and 0.9 $^{0}$C in last 23 years at Bajaura.

**Table:** Days to flowering and maturity as affected by climate change

| **Crop** | **Days To Flowering** | **Days to Maturity** | **Temperature change ($^{0}$C) during crop season** | |
|---|---|---|---|---|
| **RABI SEASON CROP** | | | | |
| **Wheat at Palampur valley** | | | **Maximum** | **Minimum** |
| Early sown Varity (VL-616) | -25.2 | -18.5 | +2.3 | +1 |
| Timely sown wheat (HS 290) | -19.1 | +4.4 | +2.3 | +1 |
| Late sown wheat (HS 295) | -3.2 | -9.2 | +2.3 | +1 |
| **Linseed at Palampur valley** | | | | |
| Jeewan | -2.6 | -9.4 | +2.3 | +1 |
| Surbhi | -13.3 | -13.1 | +2.3 | +1 |
| Janaki | -7.1 | -6.7 | +2.3 | +1 |
| Nagarkot | -3.0 | -4.2 | +2.3 | +1 |
| **Barley at Kullu valley** | | | | |
| (Dolma) Kullu Valley | 10.6 | 26.2 | -2.0 | +0.4 |
| **KHARIF SEASON CROP** | | | | |
| **Soybean at Palampur valley** | | | | |
| Soybean (Bragg) | 5.4 | 1.9 | +1.0 | -0.2 |
| Soybean (Punjabi-1) | 8.5 | 10.7 | +1.0 | -0.2 |
| **Rice at Palampur valley** | | | | |
| Rice (K-39) | -0.1 | - | +1.0 | -0.2 |
| Rice (Himdhan) | -10.8 | - | +1.0 | -0.2 |
| **Maize at Kullu valley** | | | | |
| Early maturing maize (Early composite) | -0.4 | +8.9 | -0.6 | -0.9 |
| Medium maturing maize (Navjot) | +2.6 | -1.0 | -0.6 | -0.9 |
| Medium maturing maize (Parvati) | +6.1 | -4.6 | -0.6 | -0.9 |

**Sensitivity analysis of climate parameters and productivity of major crops**

The impact of rainfall was assessed on rice, wheat & maize yield.

**Palam Valley**

**Rice**: The yield of rice increased in general for fifteen years and rainfall impact was significant in the variations in the rice yield. The productivity sensitivity with Kharif rainfall showed positive rate of 0.261 every year.

**Maize**: Maize yield showed decreasing sensitivity rate of 0.0121 with kharif rainfall. In general productivity increased with decrease in rainfall.

**Wheat**: Wheat yield during rabi season showed positive sensitivity rate with the rainfall. Reduction in *rabi* season rainfall had significant impact on yield of wheat with one unit change in rainfall i.e. ten percent rainfall change causing thirty percent reduction in wheat productivity. The rate of change was 0.289 per year.

**Fatehpur valley**

**Rice**: In general rice yield increased at the rate of 24.8 kg per year but impact of rainfall variability was small. However, 10 per cent decrease/ increase in rainfall caused 5-7 per cent increase or decrease in yield. In general, productivity decreased with decrease in rainfall.

**Maize**: In general yield increased in last fifteen years but the impact of rainfall variability on yield variation was not significant. The negative deviations in rainfall showed an increase in productivity and vice versa.

**Wheat**: Wheat yield was almost stable in last fifteen years but rainfall variability caused some increase in yield with increase in rainfall showing positive sensitivity rate with rainfall.

**Bajaura Valley**

**Rice**: In general rice yield increased in Kullu valley. Rainfall detrending indicated change in yield at the rate of 0.118 kg with per unit change in rainfall. Yield pattern of rice showed that increasing trend in yield with increasing trend in rainfall.

**Maize**: Maize yield trends indicated an increase in yield. Maize yield decreased with increase in rainfall.

**Wheat**: Wheat yield also followed similar trend as observed in maize. The sensitivity rate of wheat yield with rainfall was 0.131kg.

**Theog Region:**

No significant impact was observed on rice and maize yield. However, wheat yield showed significant change due to rainfall deviations. The sensitivity rate of change was 0.495 with rabi total rainfall.

**Future Climate parameters scenarios (IPCC) for 2020, 2050 and 2080 for Himachal Pradesh**

**Future Projections of climate change parameters in H.P.**

The climatic projections developed by IPCC for different climate parameters for Himachal Pradesh were derived for Himachal grid data using spatial reference in Latitude and Longitude. The grid size is 3.75 degree in longitude and 2.5 degree in latitude for climate parameters projections. Himachal Pradesh lies between $75^0$.5'E to $79^0$E longitudes and $30^0$5'N to $33^0$5'N latitude one grid covers the major part area of H.P. There are five climate scenario developed by IPCC for the future climate of the world (i.e. 2020, 2050 & 2080).

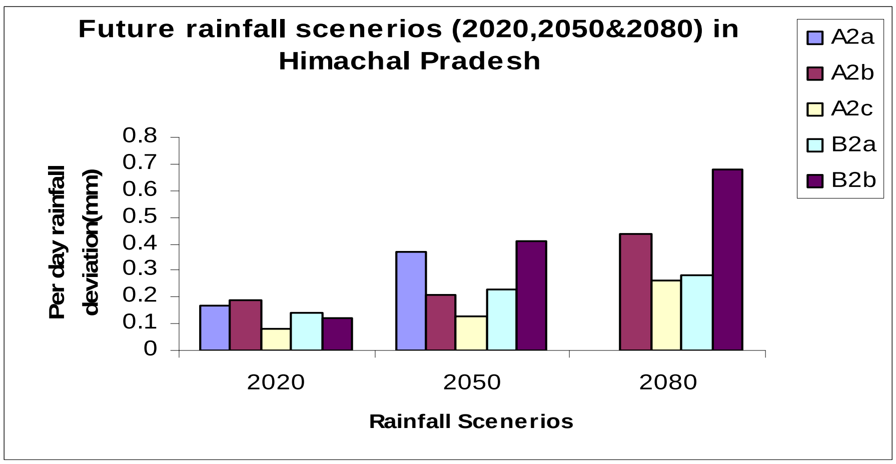
**Maximum temperature:** Surface air temperature shows increasing trends in all the scenarios for 2020, 2050 and 2080. The maximum temperature projections on per day basis are 0.72 to 1.3 Kelvin per day for 2020 in all the scenarios. *A2C scenarios* projected the maximum rise of $1.3^0$C for 2020. The projections for 2050 and 2080 are 1.13 to 2.12 Kelvin and 1.90 to 3.98 Kelvin respectively. Amongst the scenario *A2C* shows maximum increase for 2050 and 2080.

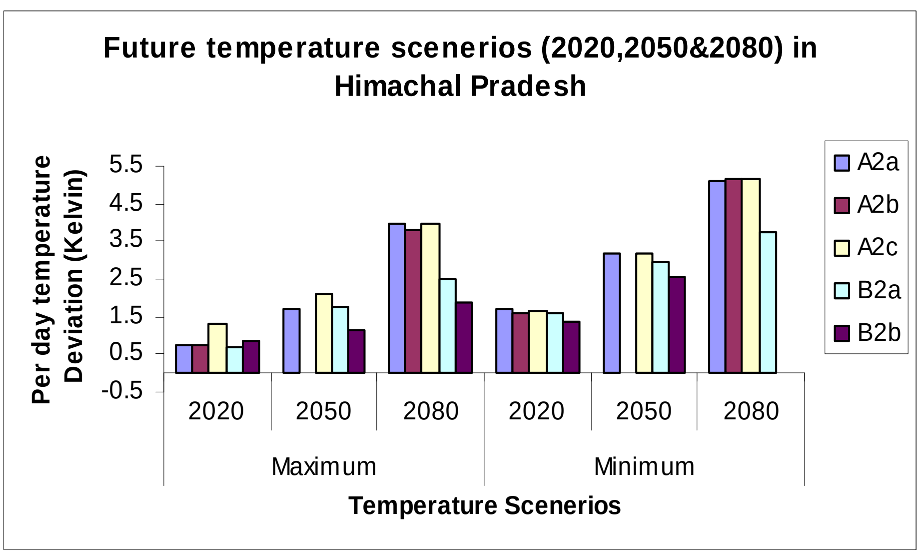
**Minimum temperature:** projections are also showing increasing trends but magnitude of increase is higher than maximum temperature. For 2020, 2050, 2080 it ranges between 1.35 to 1.72, 2.54 to 3.19 and 3.74 to 5.18 respectively in all the scenarios. A2 scenario showed the higher range of increase. These projections also verifies the increasing trends work for 1973 to 2004 from different sites of H.P. the temperature increase was 0.7 to 4.8$^0$C in last 30 years in H.P. and the magnitude is more than minimum temperature.

**Precipitation**

Precipitation is expressed in mm per day. The values projects increase or decrease of rainfall for the baseline data (1969-1990) on daily basis. For 2020, an *A2C* scenario shows decrease in rainfall for H.P. whereas all other scenarios shows increase in daily rainfall (0.12 to 19 mm).

The projections for 2050 and 2080 showed increasing trends of annual average daily rainfall (0.13 to .41mm) for 2050 and 0.28 to 0.68 mm 2080. These projections are not corroborated with our observed data. The rainfall in all the sites of study shows decreasing trends in last 2 to 3 decades observed data from different elevation zones of H.P.



**Impact of future climate on productivity of major crops based on sensitivity analysis in Himachal Pradesh**

Rainfall sensitivity analysis was carried out for different elevation zones of H.P. and then sensitivity of rainfall was assessed for major crops productivity for future climate of 2020, 2050 and 2080.

**Impact of future projections of rainfall on crop productivity**

**Wheat:** The wheat crop yield showed reduction in productivity in all scenarios for future rainfall of 2020, 2050 and 2080 at elevation of 700 to 1200 masl. In all other elevation above 1200m and below 700masl showed increase in crop productivity. The reason ascribed to this that Palampur received more than 800 mm rainfall in rabi season. Whereas in other altitudinal zone rainfall during rabi is less than 300mm. The magnitude of decrease in yield with increase of rainfall was highest in 2080 followed by 2050 and 2080.

**Rice**: The rice crop productivity would increase at Palampur (700-1200masl) and above 1500 masl. The productivity showed decrease at Dhaulakuan and Bajaura region, which lies at 1500 and below 700 masl. The magnitude of increase or decrease was highest in 2080 followed by 2050 and 2020.

**Maize**: Maize productivity with respect to future rainfall would increase at Bajaura and Dhalakuan whereas other zone 700-1200 and above 2000masl showed decrease in productivity in 2020, 2050 and 2080. The magnitude of increase and decrease is highest during 2080 followed by 2050 and 2020.

**Impact of future projections of temperature on crop productivity**

**Maximum temperature:**
Future climatic scenarios predict increase in the order of 1.5 in 2020, 2.7 in 2050 and 5.6 in 2080 Kelvin in daily maximum temperature in all grids of Himachal Pradesh. The impact of future temperature increase was assessed using detrending techniques first to evaluate the sensitivity of parameters and then using scenarios for 2020,2050 and 2080 for predicting trends in productivity of major crops viz. wheat, rice and maize.

**Wheat**: Wheat productivity showed increase in places up to 1500 masl and then decrease or negative sensitivity with respect to maximum temperature for future in all scenarios. Wheat yield projections are towards decreasing trends in 2020, 2050 and 2080.

**Rice**: Rice productivity in 2020, 2050 and 2080 in all scenarios showed decrease above 700 masl whereas in the areas below 700m, projections are for increase in yield. The magnitude of increase or /decrease observed more in 2080 followed by 2050 and 2020.

**Maize**: Maize productivity for future climate 2020, 2050 and 2080 projects an increase in all scenarios and at all elevation zones except for the areas between 700-1200 masl which is the region experiencing higher rainfall (greater than 2000mm) during crop season.

**Minimum temperature:**

Future climatic scenarios predict increase in the order of.7 to 1.3 in 2020, 1.3 to 2.3 in 2050 and 2.5 to 4.0 in 2080 Kelvin in daily maximum temperature in all grids of Himachal Pradesh.
The magnitude of minimum temperature projections is more than maximum temperature.
**Wheat**: The impact of increasing minimum temperature was more evident up to 1500 masl. Above 1500 masl, projections for wheat productivity showed decrease in 2020, 2050 and 2080 scenarios.
**Rice**: The increase in minimum temperature predicts decrease in productivity in areas above 700 masl. The areas like Dhaulakuan showed increase in productivity in all scenarios. Above 2000 masl, the magnitude of sensitivity is higher in 2020 followed by 2050 and 2080.
**Maize**: The increase in minimum temperature in future predicts increase in maize productivity in all the elevation. The minimum temperature increase would benefit the crop productivity.
**Soil Nutrients:**
The sensitivity for rainfall and temperature was used for future projections of status soil nutrients. The sensitivity analysis of rainfall and temperature with soil nutrients viz. N, P, K, pH and organic carbon were carried out for last 30 years data of crop and weather for Palampur region.

**Future projections with rainfall:**

The projections for 2020, 2050 and 2080 for all climate scenarios showed decrease in organic carbon status. The sensitivity of rainfall for organic carbon showed increase which might cause reduction in status of organic carbon. The magnitude is more as the prediction period increase i.e. highest at 2080. Similarly, projections of Nitrogen, Phosphorus and pH status showed decreasing trends of sensitivity of rainfall in all scenarios of climate projections for 2020, 2050 and 2080.This indicate that with increase in rainfall, sensitivity might increase to negative direction. The projections for potassium are contrary to the N and P. The sensitivity showed increase with increase in rainfall in future and help in increasing the status of potassium into soil.

**Farmers' perception of climate change**

Farmers in the five selected area were exclusively questioned about last fifteen years' climate change. In the Fatehpur valley, more than 90 percent farmers were of the opinion that uneven distribution of rainfall during the monsoon season, delay in the onset of the winter season, short winter period and the temperature above the normal were observed in the last 10-15 years. The farmers of the Theog region had similar observations in addition to the reduction of snowfall in winter. The short winter period, reducing snowfall in winter and increasing temperature during the summer season were among the most visible signs of changing climate as opined by almost all the farmers in Bajaura valley. The similar signs of changing climate in Palam valley were also observed by the farmers during the last 10-15 years. In Lahaul valley more than 80 percent of sample farmers were of opinion that reducing snowfall in the winter and delay in the start of the winter season, the threat of floods in the valley in the last 4-5 years is also among the signs of changing climate in the valley.

**Farmers perceptions regarding climate change** (Percent multiple response)

| **Particulars** | **Fatehpur Valley** | **Theog Region** | **Bajaura Valley** | **Palam valley** | **Lahaul Valley** |
|---|---|---|---|---|---|
| Increasing temp. during summer | 88 | 80 | 85 | 90 | - |
| Prolonged summer season | 56 | 48 | 66 | 62 | - |
| Short summer season | 5 | 8 | 10 | 5 | - |
| Delayed in the onset of rainy season | 66 | 80 | 85 | 88 | - |
| Uneven distribution of rainfall | 90 | 96 | 88 | 98 | - |
| Insufficient rainfall during rainy | 58 | 72 | 77 | 95 | - |
| Delay in the outset of winter season | 92 | 48 | 68 | 45 | 60 |
| Very low temp. in winter season | - | 12 | - | 10 | 80 |
| Short winter period | 92 | 88 | 94 | 88 | 80 |
| Temp. above normal during winter | 92 | 88 | 92 | 96 | 15 |
| Reducing snowfall in winter | - | 100 | 100 | - | 88 |
| High humid weather | 66 | 36 | 40 | 75 | 22 |
| Increasing foggy days in winter | 66 | 52 | 16 | 22 | - |
| Increasing cloudy days in winter | 56 | 18 | 16 | 15 | 28 |
| Unpredictable rainfall | 66 | 52 | 76 | 65 | - |
| Threat of floods | 58 | 50 | 88 | - | 88 |
| High velocity winds | 18 | - | - | 20 | - |
| Mud slides | - | - | - | - | 20 |
| High intensity of rainfall | 52 | - | 20 | - | - |

**Impact on cropping pattern and income**

**FATEHPUR VALLEY (252-700m)**

The farmers' survey revealed that area under maize and paddy (basmati) reduced to the tune of 26% and 37% respectively, over one decade and the area was shifted to local paddy. Area under sugarcane also reduced by 47 percent and area shifted to wheat crop during *rabi* season other cash crops cash crops like garlic and ginger. The total farm income of an average farm reduced to small extent (0.14 percent) in the present period. However, the total farm income of marginal and small farmers has recorded an increase of 24 to 29 per cent in present period. The percentage of total work force engaged in agriculture sector has decline to about 57 per cent in present as against about 87 per cent in the past.

**PALAM VALLEY (700-1500m)**

The rain-fed paddy area has reduced to the extent of about 86 per cent. The productivity of all the crops has reduced to the extent of about 27 to 50 per cent in the present period. The total farm income has registered a decrease of about 32 per cent. About 60 per cent of total work force was found to engage in agriculture and allied activities as against about 71 per cent in the past.

**BAJAURA VALLEY (1500-2200m)**

A remarkable increase in the area under off-season vegetable cultivation has been noticed in the present cropping pattern. The food crops and fruits area was shifted the off season vegetable cultivation. The decline in area under apple and other fruits was comparatively higher in marginal and small farmers. The productivity of apple has recorded a decrease of about 2 to 3 per cent over the past period and the maximum decrease of about 4 per cent has been noticed in marginal farmers. The total farm income on an average has shown a marginal reduction of about 4 per cent in present period.

**THEOG REGION (Above 2000m)**

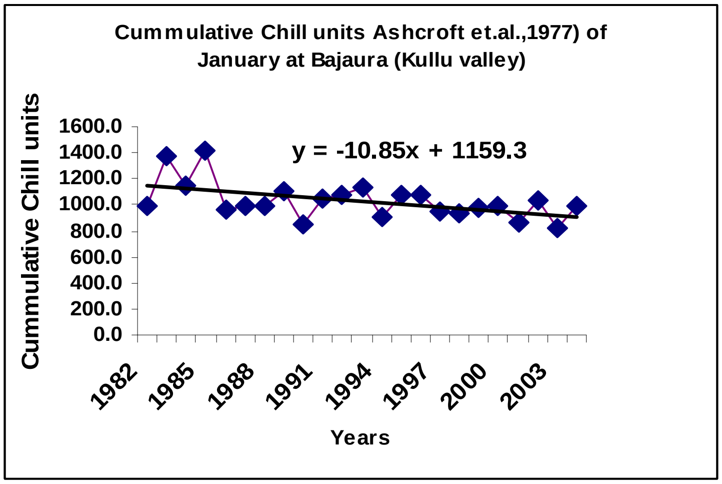
The off season vegetables have shared more than 84 per cent of the area under field crops. The area under cereals has declined to the extent of 80 per cent. The total area under apple and other fruits has recorded no change over the period, however, across different categories of farmers, the decline in area was more in marginal farmer (33.33 per cent) than small (5.59 per cent) and large farmers (4.91 per cent). There has been a 2 to 3 per cent decline in the yield of apple.

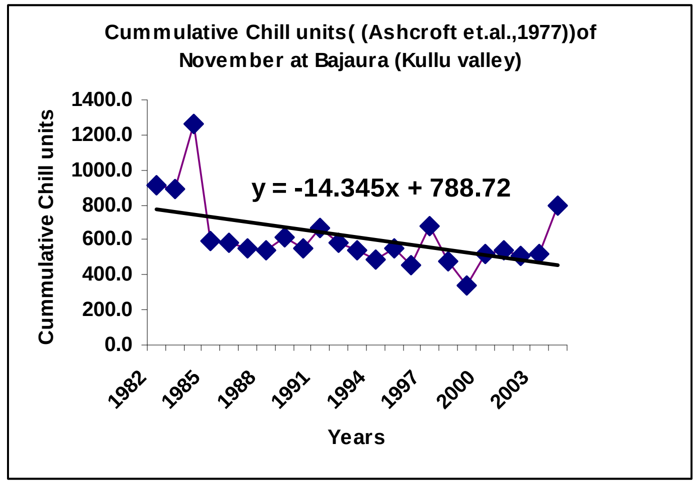
The total farm income on an average farm remained stagnant but in the large category farmers, it has registered an increase of more than 17 per cent due to more income from off-season vegetables. The share of the fruits crops, mainly apple has come down to 33 per cent (present period) from 59 per cent (past periods)

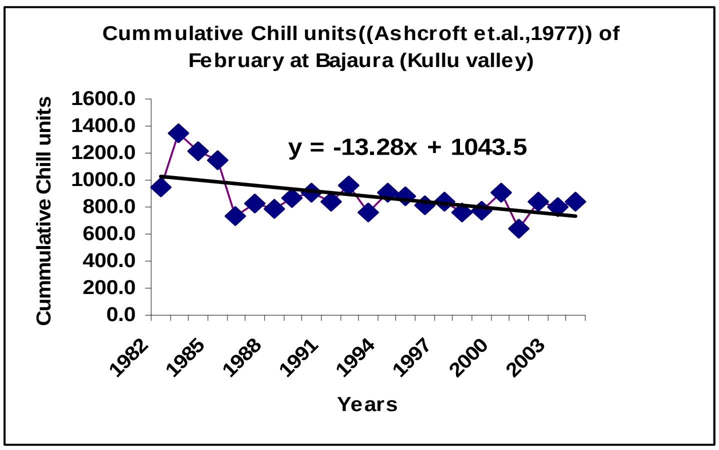
**LAHAUL VALLEY (Above 2500m)**

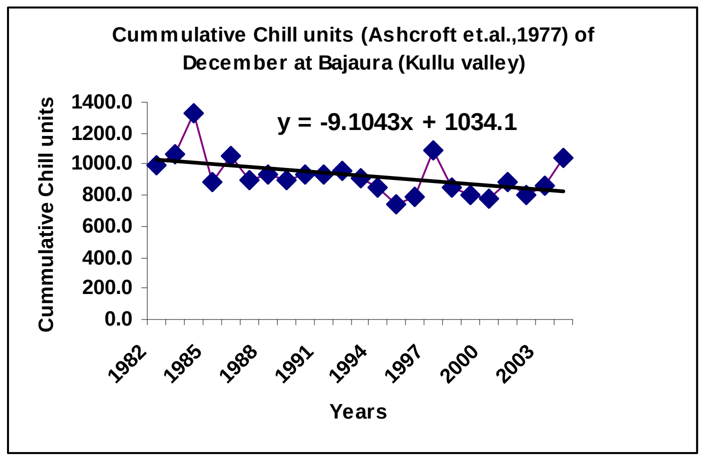
The area under cash crops mainly potato and peas in the present cropping pattern increased to the extent of about 8 to 9 per cent. The area under apple in the present cropping pattern has also recorded a remarkable increase of more than 122 per cent. The productivity of cash crops like potato and peas has declined by more than 11 to 15 per cent over a decade period. The productivity of apple has also recorded a marginal decline of 1 to 2 per cent in the present period. The total farm income of the farmers has registered an increase of about 32 per cent over the period. The percentage increase in the income was much higher in small and large farmers than the marginal farmers. The percentage of total work force engaged in agriculture has declined while in the activities of trade/business and in labour it has doubled in the present period.

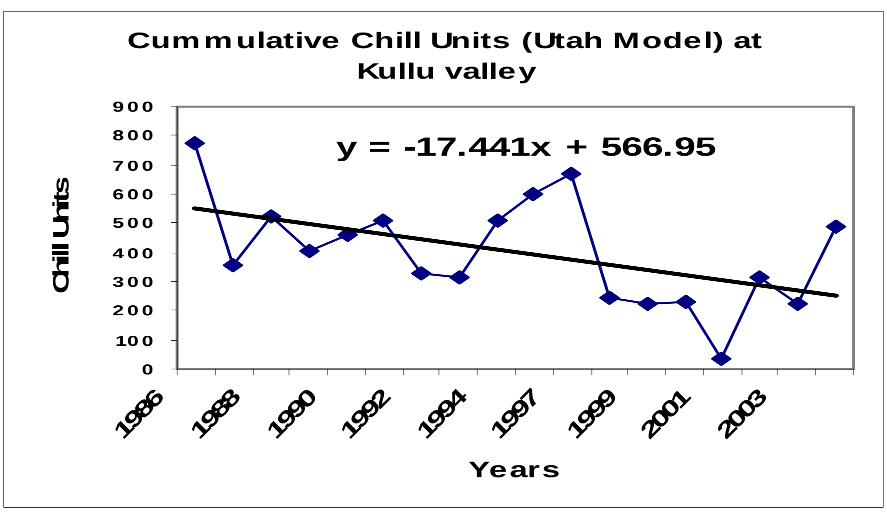
## Appendix I
## Chilling units Requirements calculations at Bajaura (Kullu valley) Region



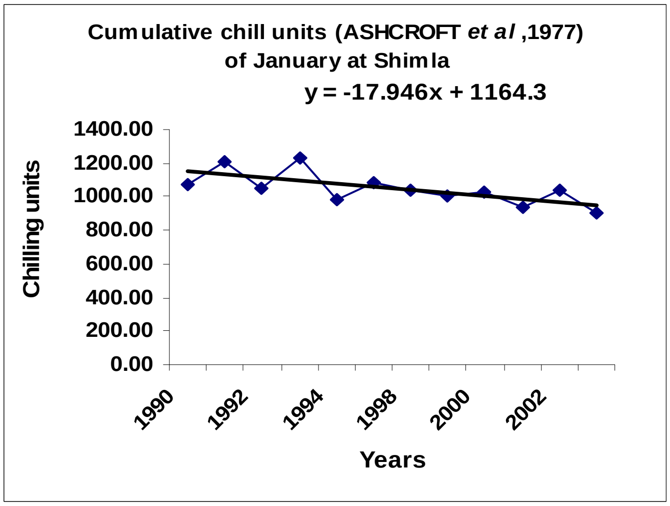



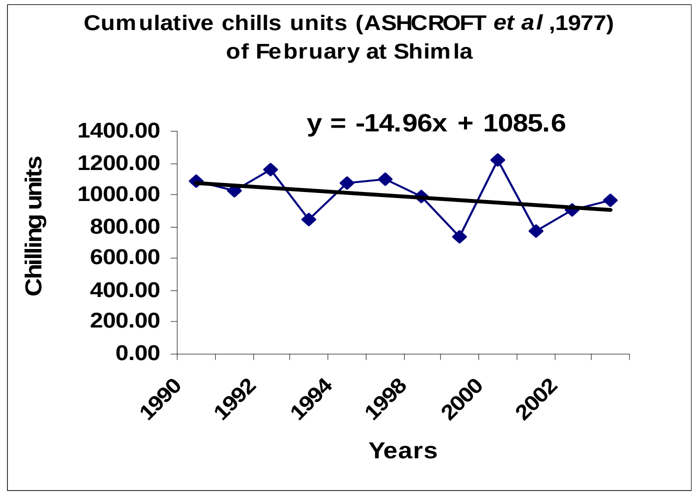



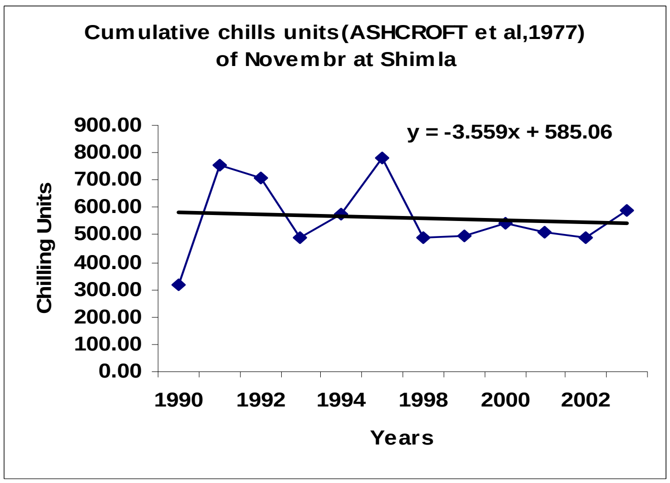



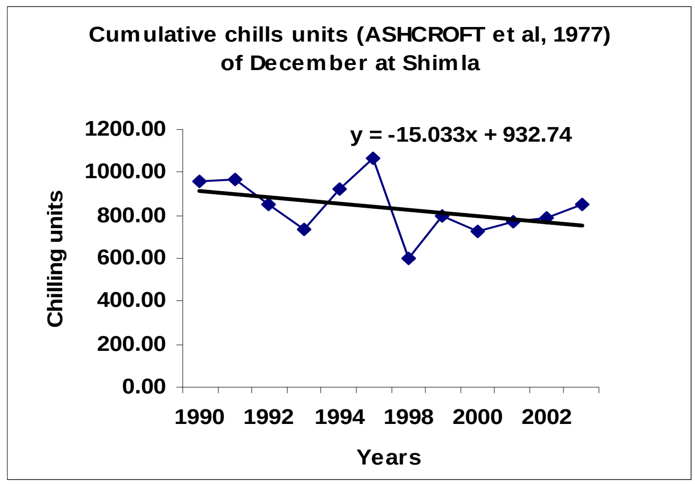



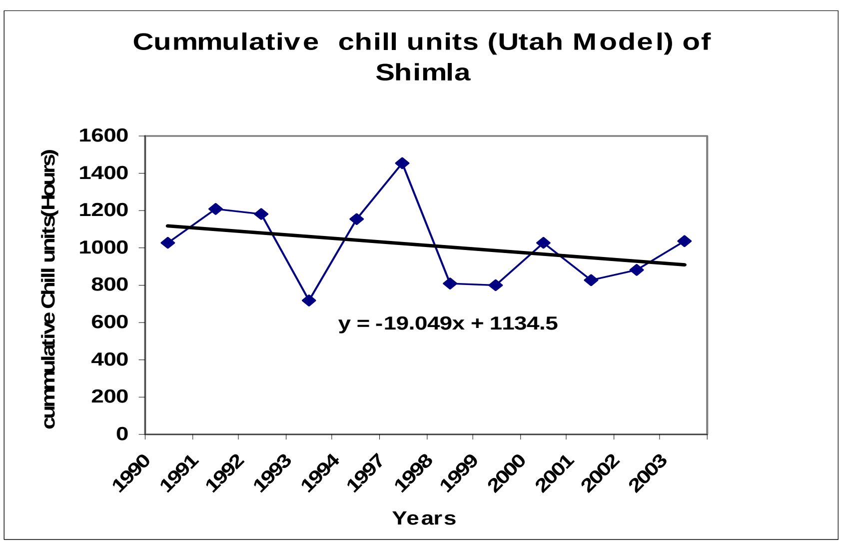
**Appendix I (contd.)**
**Chilling units Requirements calculations at Shimla Region**



# Dr. Y. S Parmar University of Horticulture and Forestry Nauni, Solan

**Objective:** Impact of climate change on apple productivity and trend in Himachal Pradesh.

**Trends in Climate Change in Himachal Pradesh and adjoining plains.**

The general climate of Himachal Pradesh varies from sub-tropical to dry temperate with an altitudinal range from about 400-3500 m asl. To analyze the past trends of climate change in north- western Himalayan and adjoining plain the data on temperature (maximum and minimum), rainfall and snowfall was collected from the following zones:

| | | |
|---|---|---|
| Subtropical plain | - | Chandigarh |
| Subtropical low hill zone | - | Bilaspur ( H P ) |
| Sub humid mid hill zone | - | Kullu (H.P) |
| Sub humid mid hill zone | - | Solan ( H P ) |
| Wet temperate high hills zone | - | Shimla (H P.) |
| Dry Temperate high hills zone | - | Kinnaur (H.P.) |

Data pertaining to different meteorological variables has been analysed and averaged for a time interval of five years.


**Fig-1 Agro climatic zones of Himachal Pradesh**

**a) Subtropical plain**

The average maximum temperature in the foothills of Himachal Pradesh was 29.9 °C and 30.5 °C during 1981-85 and 2001-04, respectively. It has increased by 0.6 $^0$C during 2001-04 over 1981-85 periods. Whereas, the minimum temperature was 17.5$^0$C and 15.5 °C during 1981-85 and 2001-04, respectively (Fig 2). Thus, it has decreased by 2.0$^0$C during the last 20 years. The average rainfall in the same time interval has increased from 1110 to 1206mm (Fig 3).

**b) Subtropical low hill**

The average maximum temperature in low hill subtropical zone during 1991-95 was 27.7 °C, which has increased to 28.5 $^0$C during 2001-04. On the other hand, minimum temperature has shown lesser variation in comparison to maximum temperature. It remained at the level of 13.2 **°C** during 1981-85 and 13.1$^0$C during 2001-04. Thus maximum temperature has increased by 0.8 $^0$C and minimum temperature has decreased by O.1 during 2001-04 over 1991-95 periods. Rainfall decreased by 102.92 mm over the same period (Fig 4-5).

**c) Sub-humid mid hill zone**

**i) Kullu:** The average maximum temperature in sub-humid mid hill zone has increased by 1.5 °C during 2001-04 (26.5 $^0$C) over 1991-1995 (25.0 $^0$C) (Fig 6). The minimum temperature during 1991-95 was 9.3 °C, which increased to 9.9 $^0$C during 2001-04. Thus, it has increased by 0.6 °C. The average rainfall during 1991-95 was 972.58 m, but now (2001-04) it has receded down to 708.37 mm (Fig 7).

**ii) Solan:** There was considerable increase in the average maximum temperature in sub-humid mid hill zone of Himachal Pradesh. The average maximum temperature has increased to the tune of 1.6 $^0$C (24.8 $^0$C during 1986-90 and 26.4 $^0$C during 2001-04). On the other hand, the change in minimum temperature was in the reverse order. It has come down by 0.3 °C (12.0 $^0C$ during 1986-90 and 11.7 °C during 2001-04) (Fig 8). The average rainfall during 1986-90 was 1504.32 mm, which has drastically come down to 1007.25 mm during 2001-04 (Fig 9).

**d) Wet temperate high hills zone**

In the temperate wet zone, average maximum temperature during 1976-80 was 17.6 $^0$C, which has shown an increase of 2.8 $^0$C during 2001-04 (20.4 $^0$C) (Fig 10). The minimum temperature has increased by 0.6 $^0$C. It was 8.4 °C during 1976-80 and 9.0 $^0$C during 2001-04. The rainfall has declined from 1245 mm (1976-80) to 1058 mm (2001-04)(Fig 12). Average snowfall has also shown a considerable decline (Fig 11). The average snowfall during 1976-80 was 272.4 cm. but now it has come down to the level 77.2 cm (2001-04).

**e) Dry temperate high hills zone**

In dry temperate zone the maximum temperature has shown considerable increase over the years. It was 19.8 °C during 1991-95 that increased to the level of 21.6$^O$C during 2001-04. Similarly, the minimum temperature has also increased from 0.6$^O$C (1991-95) to 1.2 °C (2001-04) (Fig 13). On the other hand precipitation has declined during the same time interval. Snowfall has come down to 398.42 cm (2001-04) from the level of 44.82 cm (1991-95) (Fig-14). Similarly, the rainfall has also shown the declining trends, it was 308.00 mm during 1991-95 and has declined to 274 15 mm during 2001-04 (Fig 15)

**Apple productivity trends of Himachal Pradesh in relation to climatic variation**

**Methodology**

Data on climatic variable viz., max and minimum temperature starting from November to March was collected from different altitude falling in temperate wet and temperate dry. Similarly, apple production data from 1980s onward was collected from major apple growing areas namely Shimla, Kullu and Kinnaur district of Himachal Pradesh. The productivity trend for the whole state was also worked out. Variablity in production and chilling unit accumulation at district, zone and state level was worked out under normal orchard situation. A case study for well managed orchard was also undertaken.

Chill Unit accumulations from November to February for winter seasons corresponding to different production years were calculated from the average maximum and minimum temperatures and the method of synthesizing hourly temperatures were used. Chill units contributes of Utah Chill Unit Model were used for computing chill unit (CU) accumulations.

**Trend line and regression equation**

1. Graph between reference years and apple productivity was plotted. From the Graph, the trend line was fitted and the value of $R^2$ was worked out

2. By substituting the value of reference year as X value in the trend equation, the value of trend predicted productivity was calculated.

3. The value of Normalized Productivity Deviation (NPD) was determined by using the following formula:

$$\text{NPD} = \frac{(\text{Productivity} - \text{Trend Predicted Productivity})}{(\text{Trend Predicted Productivity})}$$

4. Graph between reference year and NPD was plotted.

5. CU Deviations were calculated by using the following formula.

$$\text{CU Deviation} = \frac{\text{Total CU} - \text{Average CU}}{\text{Average CU}}$$

6. Graph between NPD and CU deviation was plotted.

7. Regression equation between CU Deviation and NPD was calculated.

8. The slope of the regression equation indicated the sensitivity of productivity with respect to CU accumulations.

**Result:**

**A. Shimla**

Data pertaining to the relationship of chill units with respect to apple productivity of Shimla district are presented in Table 1 and Fig 2. The perusal of data (Table 1 and Fig 3) indicates that there was a decreasing trend of productivity with respect to reference years. The slope of the regression equation (0.131) shows that the productivity was affected by the reference production years to little extent. Similarly, the slope of the regression equation between NPD (Normalized Productivity Deviation) and CU Deviation indicates (Fig 4) that the productivity was sensitive to CU deviation.

**Table 1**. Relationship of chill units with respect to apple productivity (Shimla) in Himachal Pradesh

| Production Year | Ref. Year | Productivity (t/ha) | Trend predicted productivity | N.P.D. | Total C.U. | C.U. Deviation |
|---|---|---|---|---|---|---|
| 1990-91 | 1 | 12.87 | 9.27 | 0.3883 | 2214 | 0.1634 |
| 1991-92 | 2 | 10.72 | 9.14 | 0.1729 | 1854 | -0.0257 |
| 1992-93 | 3 | 9.54 | 9.01 | 0.0588 | 2208 | 0.1603 |
| 1993-94 | 4 | 8.53 | 8.88 | -0.0394 | 2106 | 0.1067 |
| 1994-95 | 5 | 3.57 | 8.74 | -0.5915 | 1794 | -0.0573 |
| 1995-96 | 6 | 9.23 | 8.61 | 0.0720 | 2214 | 0.1634 |
| 1996-97 | 7 | 9.20 | 8.48 | 0.0849 | 2010 | 0.0562 |
| 1997-98 | 8 | 5.67 | 8.35 | -0.3210 | 1620 | -0.1487 |
| 1998-99 | 9 | 11.11 | 8.22 | 0.3516 | 2466 | 0.2958 |
| 1999-2000 | 10 | 0.86 | 8.09 | -0.8937 | 1346 | -0.2927 |
| 2000-01 | 11 | 10.88 | 7.96 | 0.3668 | 1944 | 0.0215 |
| 2001-02 | 12 | 4.14 | 7.82 | -0.4706 | 1764 | -0.0730 |
| 2002-03 | 13 | 8.21 | 7.69 | 0.0676 | 1794 | -0.0573 |
| 2003-04 | 14 | 10.11 | 7.56 | 0.3373 | 1548 | -0.1865 |
| 2004-05 | 15 | 10.58 | 7.43 | 0.4240 | 1662 | -0.1266 |

**B) Kullu**

It is evident from Table 2 and Fig 5 that the production per ha showed a slightly declining trend. Though, the regression coefficient was very weak. The slope of the regression equation (0.191) between CU deviation and NPD presented in Fig 6 depicted the sensitivity of NPD with respect to the CU deviations (Fig 7).

**Fig. 2 Apple productivity trend in Shimla district of H.P.**

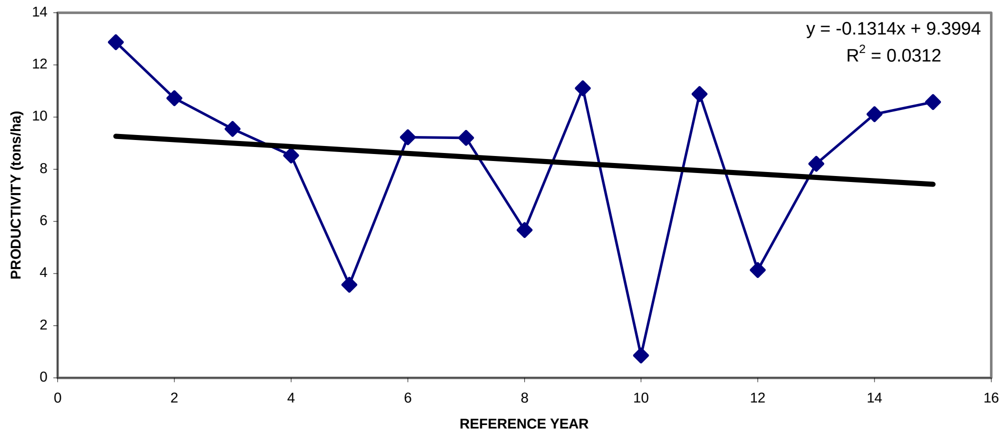



**Fig . 3 Normalised productivity deviation trends of apple production in Shimla district of H.P.**

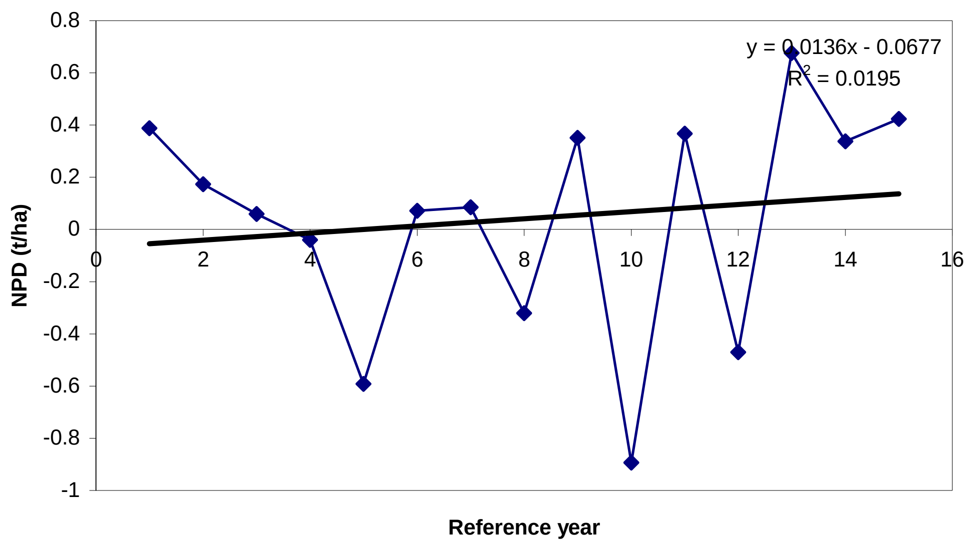


**Fig.4. Senstivity of NPD to chil unit deviation in Shimla district of (H.P.)**

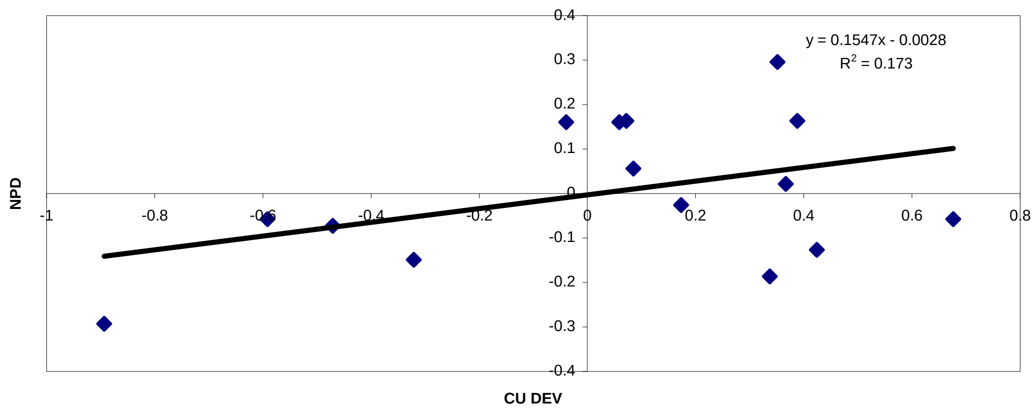



**Table 2:** Relationship of chill units with respect to apple productivity (Kullu) in Himachal Pradesh

| Production Year | Ref. Year | Productivity (t/ha) | Trend Predicted Productivity | N.P.D. | Total C.U. | C.U. Deviation |
|---|---|---|---|---|---|---|
| 1990-91 | 1 | 6.90 | 5.31 | 0.2994 | 1881 | 0.3126 |
| 1991-92 | 2 | 5.95 | 5.27 | 0.1290 | 1668 | 0.1640 |
| 1992-93 | 3 | 5.65 | 5.23 | 0.0803 | 1938 | 0.3524 |
| 1993-94 | 4 | 7.49 | 5.19 | 0.4432 | 1233 | -0.1396 |
| 1994-95 | 5 | 1.77 | 5.15 | -0.6563 | 1317 | -0.0809 |
| 1995-96 | 6 | 4.1 | 5.11 | -0.1977 | 1560 | 0.0886 |
| 1996-97 | 7 | 4.9 | 5.07 | -0.0335 | 1501 | 0.0475 |
| 1997-98 | 8 | 5.31 | 5.03 | 0.0557 | 1257 | -0.1228 |
| 1998-99 | 9 | 7.17 | 4.99 | 0.4369 | 1797 | 0.2540 |
| 1999-2000 | 10 | 0.52 | 4.95 | -0.8949 | 1065 | -0.2568 |
| 2000-01 | 11 | 4.11 | 4.91 | -0.1629 | 1398 | -0.0244 |
| 2001-02 | 12 | 1.98 | 4.87 | -0.5934 | 933 | -0.3489 |
| 2002-03 | 13 | 5.17 | 4.83 | 0.0704 | 1434 | 0.0007 |
| 2003-04 | 14 | 6.09 | 4.79 | 0.2714 | 1245 | -0.1312 |
| 2004-05 | 15 | 8.39 | 4.75 | 0.7663 | 1272 | -0.1124 |

**Fig.5 Apple productivity trend in Kullu district of H.P.**

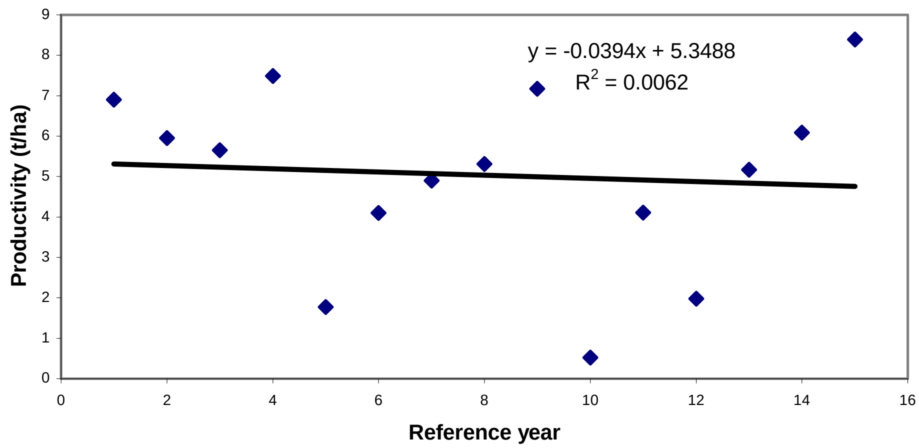



**Fig 6. Normalised productivity deviation trends of apple production in Kullu district of H.P.**

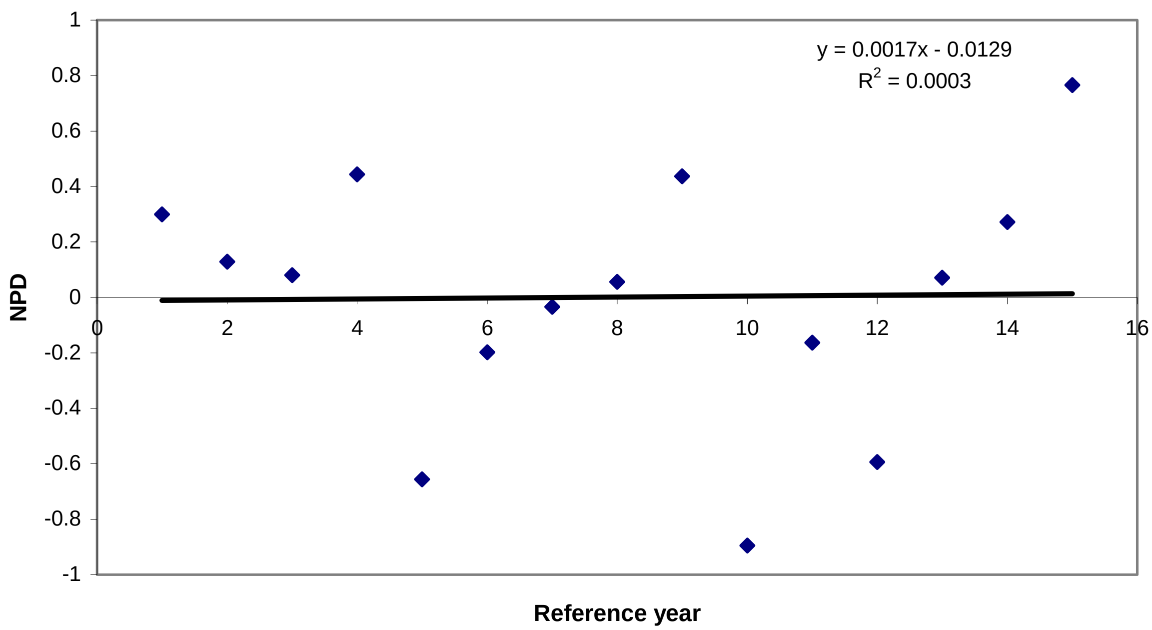
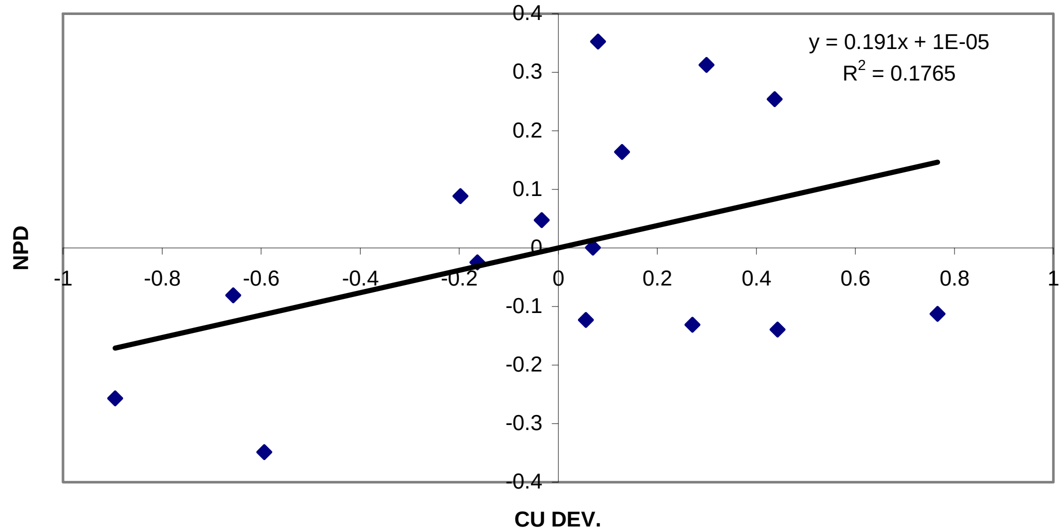


Fig.7 Senstivity of NPD to chill unit deviation in Kullu district of (H.P.)




**Temperate zone (Shimla +Kullu)**

The average apple productivity of Shimla and Kullu districts was compared with the mean CU accumulations of both districts(Fig. 8). The mean CU's were calculated on basis of temperature data of RHRS, Mashobra (Shimla) and IARI, Katrain (Kullu). Perusal of data presented in Table 3 reveals that the trend predicted productivity declined with respect to reference year and the slope of regression equation ($R^2$= 0.0017) indicate that there was slight decline in normalized apple productivity deviation with each progressing year (Fig. 9). The relationship between NPD and CU deviation shows that NPD was quite sensitive to CU deviation (Fig.10) having slope value of 0.245.

**C. Kinnaur**

Relationship of CUs with respect to apple productivity Kinnaur district was analysized for 9 years w.e.f 1996-97 to 2004-05. Contrary to other major apple producing districts of HP, the trend predicted productivity indicate increasing trend (Table 4 and Fig. 11) with the slope of regression equation (0.1398), though the regression coefficient was very poor. This indicates that very cold area is becoming more and fit for apple farming day by day. Further, the relationship between CU deviation and NPD (Fig. 12 and Fig. 13) shows very less slope value (0.012) indicating very low effect of CU deviation on NPD.

**Table 3:** Relationship of chill units with respect to apple productivity (Shimla & Kullu) in Himahcal Pradesh

| Production Year | Ref. Year | Productivity (t/ha) | Trend Predicted Productivity | N.P.D. | Total C.U. | C.U. Deviation |
|---|---|---|---|---|---|---|
| 1990-91 | 1 | 9.89 | 7.28 | 0.3585 | 1992 | 0.2528 |
| 1991-92 | 2 | 8.34 | 7.20 | 0.1583 | 1730 | 0.0881 |
| 1992-93 | 3 | 7.58 | 7.11 | 0.0661 | 2028 | 0.2755 |
| 1993-94 | 4 | 8.01 | 7.03 | 0.1394 | 1524 | -0.0415 |
| 1994-95 | 5 | 2.67 | 6.94 | -0.5720 | 1476 | -0.0717 |
| 1995-96 | 6 | 6.67 | 6.86 | -0.0277 | 1778 | 0.1182 |
| 1996-97 | 7 | 7.06 | 6.77 | 0.0428 | 1671 | 0.0509 |
| 1997-98 | 8 | 5.49 | 6.69 | -0.1794 | 1378 | -0.1333 |
| 1998-99 | 9 | 9.14 | 6.61 | 0.3828 | 2020 | 0.2704 |
| 1999-2000 | 10 | 0.69 | 6.52 | -0.8942 | 1159 | -0.2711 |
| 2000-01 | 11 | 7.50 | 6.44 | 0.1646 | 1580 | -0.0063 |
| 2001-02 | 12 | 3.06 | 6.35 | -0.5181 | 1210 | -0.2390 |
| 2002-03 | 13 | 6.69 | 6.27 | 0.0670 | 1554 | -0.0226 |
| 2003-04 | 14 | 8.10 | 6.18 | 0.3107 | 1346 | -0.1535 |
| 2004-05 | 15 | 9.49 | 6.10 | 0.5557 | 1410 | -0.1132 |

**Fig. 8 Combined apple productivity trend of Shimla and Kullu district of H.P.**

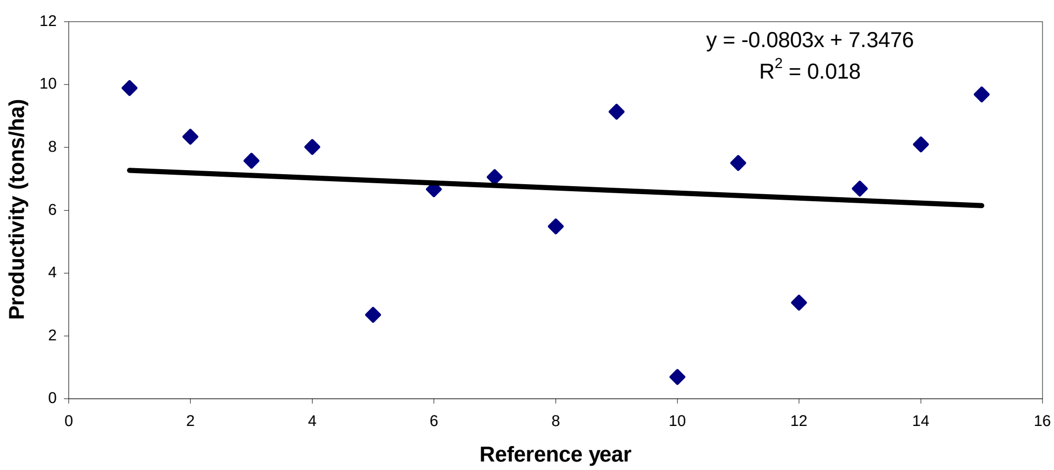


**Fig. 9 Normalised productivity deviation trends of apple production in Shimla and kullu districts of H.P.**

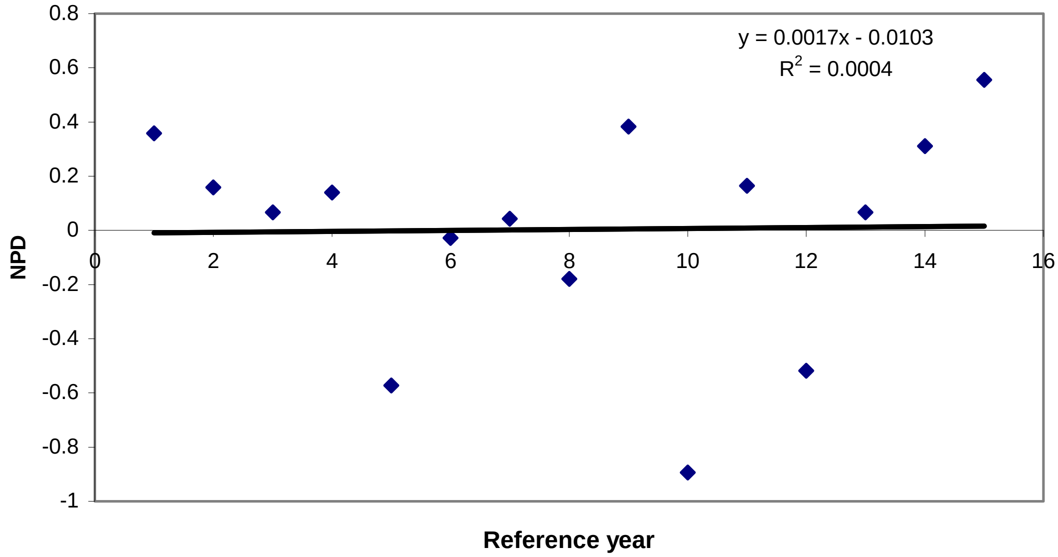



**Fig.10 Senstivity of NPD to chil unit deviation inShimla plus Kullu district of H.P.**

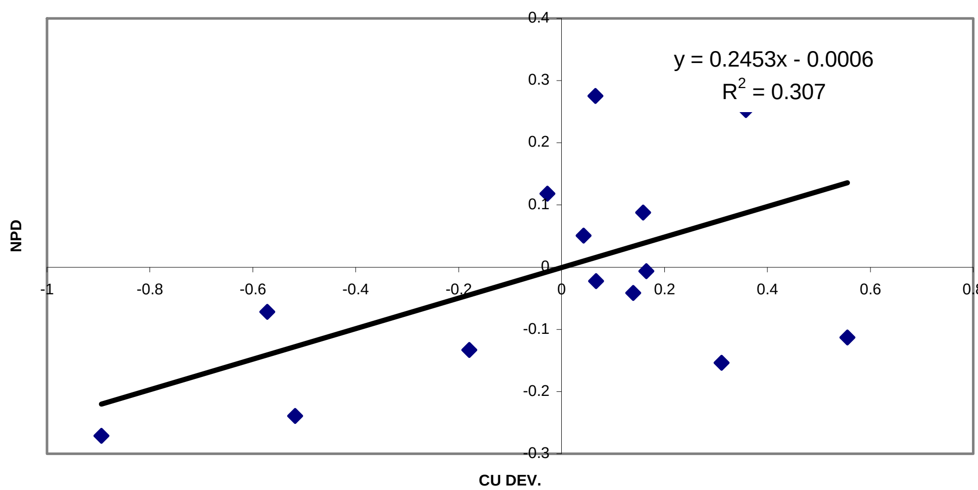


**Table 4:** Relationship of chill units with respect to apple productivity (Kinnaur) in Himachal Pradesh

| Production Year | Ref. Year | Productivity (tones /ha) | Trend Predicted Productivity | N.P.D. | Total C.U. | C.U. Deviation |
|---|---|---|---|---|---|---|
| 1996-97 | 1 | 5.46 | 4.69 | 0.1642 | 1176 | -0.0511 |
| 1997-98 | 2 | 6.90 | 4.89 | 0.4110 | 1494 | 0.2055 |
| 1998-99 | 3 | 4.83 | 5.09 | -0.0511 | 1194 | -0.0366 |
| 1999-2000 | 4 | 3.82 | 5.30 | -0.2792 | 1314 | 0.0603 |
| 2000-01 | 5 | 5.07 | 5.50 | -0.0782 | 1428 | 0.1522 |
| 2001-02 | 6 | 4.24 | 5.70 | -0.2561 | 1182 | -0.0463 |
| 2002-03 | 7 | 4.81 | 5.90 | -0.1847 | 1272 | 0.0264 |
| 2003-04 | 8 | 6.93 | 6.11 | 0.1342 | 1134 | -0.0850 |
| 2004-05 | 9 | 7.44 | 6.31 | 0.1791 | 960 | -0.2254 |

**Overall HP state**

Overall apple productivity in Himachal Pradesh w.e.f 1980-81 to 2004-05 was compared with mean CU accumulations at RHRS, Mashobra (Shimla) and IARI, Katrain (Kullu). Perusal of data in Table 5 and Fig. 14 reveals that declining trend of production with the slope of regression equation indicating the sensitivity to the production years/references (-0.1005).

**Fig.11 Productivity trends of apple production in Kinnaur district of H.P.**

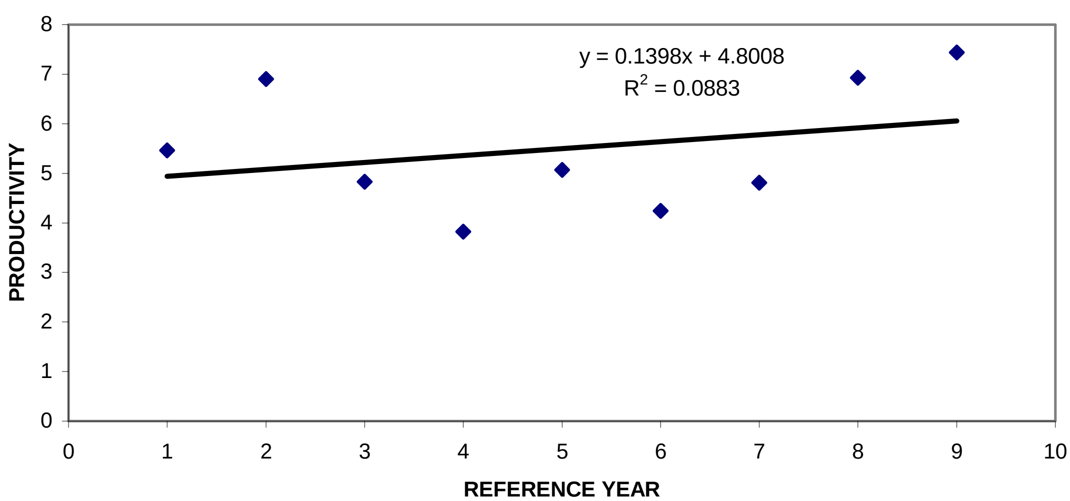


**Fig.12Normalised productivity deviation trends of apple production in Kinnaur district of H.P.**

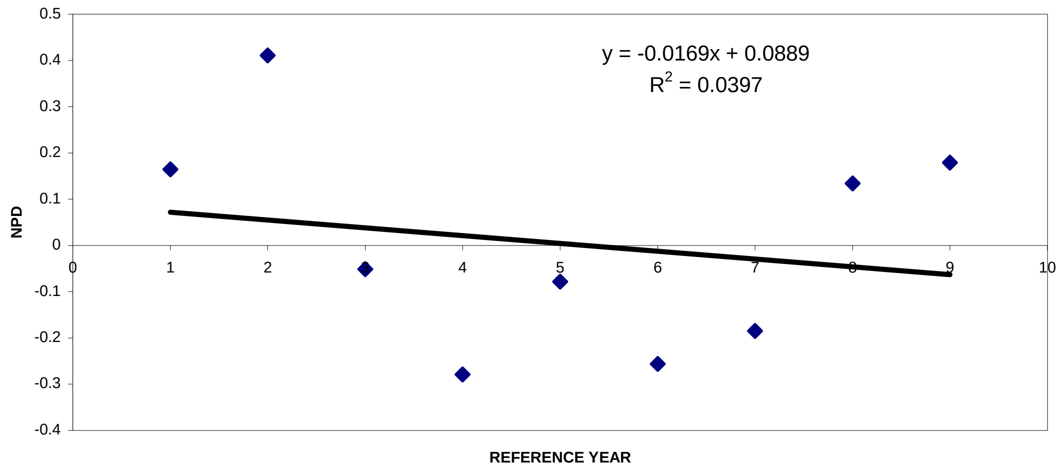
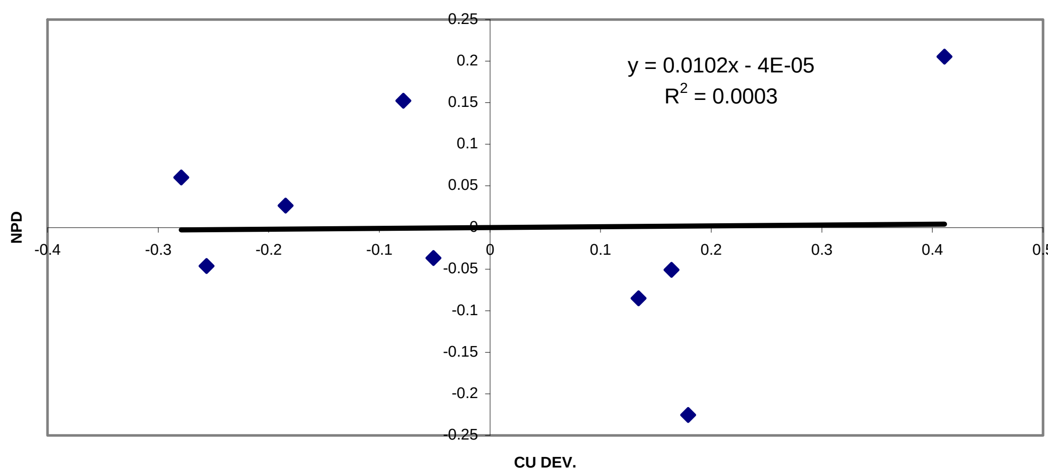



**Fig.13 Senstivity of NPD to chil unit deviation in Kinnaur district of (H.P.)**




The slope of the regression equation between NPD and reference year ($R^2$=0.0006) was low (fig.15) indicating less deviation of the NPD with respect to reference years. The fig.16 shows sensitivity that with each chilling unit deviation the production changes at the rate of 1.6 quintel / chillunit.

Fig.14 Apple productivity trend of Himachal Pradesh.

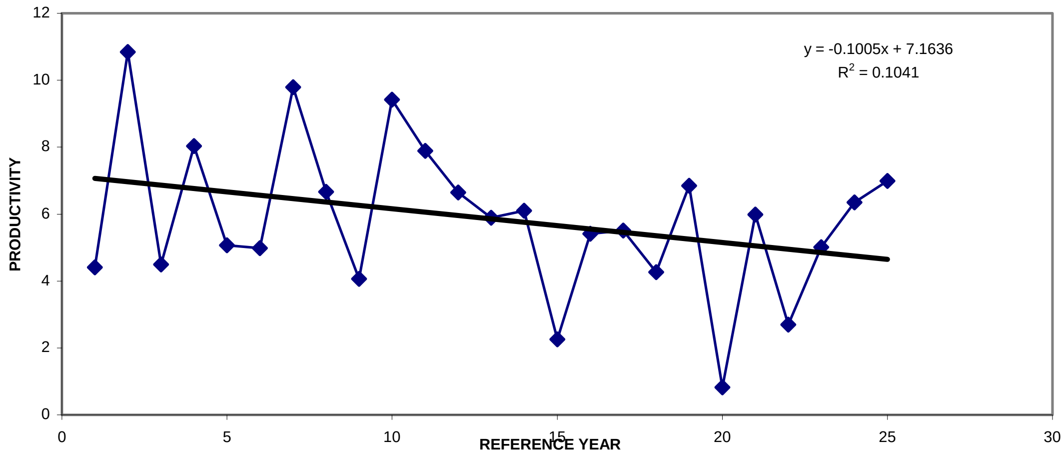



**Table 5:** Relationship of chill units with respect to over all apple productivity in Himachal Pradesh

| Production Year | Ref. Year | Productivity (Tons/ ha) | Trend Predicted Productivity | N.P.D. | Total C.U. | C.U. Deviation |
|---|---|---|---|---|---|---|
| 1980-81 | 1 | 4.41 | 7.06 | -0.3754 | 2118 | 0.0796 |
| 1981-82 | 2 | 10.84 | 6.96 | 0.5575 | 2118 | 0.0796 |
| 1982-83 | 3 | 4.49 | 6.86 | -0.3455 | 2197 | 0.1199 |
| 1983-84 | 4 | 8.03 | 6.76 | 0.1879 | 2310 | 0.1775 |
| 1984-85 | 5 | 5.07 | 6.67 | -0.2399 | 2130 | 0.0857 |
| 1985-86 | 6 | 4.98 | 6.56 | -0.2409 | 2091 | 0.0658 |
| 1986-87 | 7 | 9.79 | 6.46 | 0.5155 | 2235 | 0.1392 |
| 1987-88 | 8 | 6.66 | 6.36 | 0.0472 | 2250 | 0.1469 |
| 1988-89 | 9 | 4.06 | 6.26 | -0.3514 | 1790 | -0.0876 |
| 1989-90 | 10 | 9.42 | 6.16 | 0.5292 | 2148 | 0.0949 |
| 1990-91 | 11 | 7.89 | 6.06 | 0.3020 | 2280 | 0.1622 |
| 1991-92 | 12 | 6.65 | 5.96 | 0.1158 | 1977 | 0.0077 |
| 1992-93 | 13 | 5.89 | 5.86 | 0.0051 | 2355 | 0.2004 |
| 1993-94 | 14 | 6.10 | 5.76 | 0.0590 | 1758 | -0.1039 |
| 1994-95 | 15 | 2.46 | 5.66 | -0.5654 | 1677 | -0.1452 |
| 1995-96 | 16 | 5.41 | 5.56 | -0.0270 | 2010 | 0.0245 |
| 1996-97 | 17 | 5.51 | 5.46 | 0.0092 | 1909 | -0.0269 |
| 1997-98 | 18 | 4.26 | 5.35 | -0.2037 | 1551 | -0.2094 |
| 1998-99 | 19 | 6.85 | 5.25 | 0.3048 | 2298 | 0.1713 |
| 1999-2000 | 20 | 0.82 | 5.15 | -0.8408 | 1363 | -0.3052 |
| 2000-01 | 21 | 5.99 | 5.05 | 0.1861 | 1887 | -0.0381 |
| 2001-02 | 22 | 2.70 | 4.95 | -0.4545 | 1563 | -0.2033 |
| 2002-03 | 23 | 5.01 | 4.85 | 0.0330 | 1794 | -0.0856 |
| 2003-04 | 24 | 6.35 | 4.75 | 0.3368 | 1569 | -0.2002 |
| 2004-05 | 25 | 6.99 | 4.65 | 0.5032 | 1668 | -0.1498 |

Fig.15Normalised productivity deviation trends of apple production in H.P.

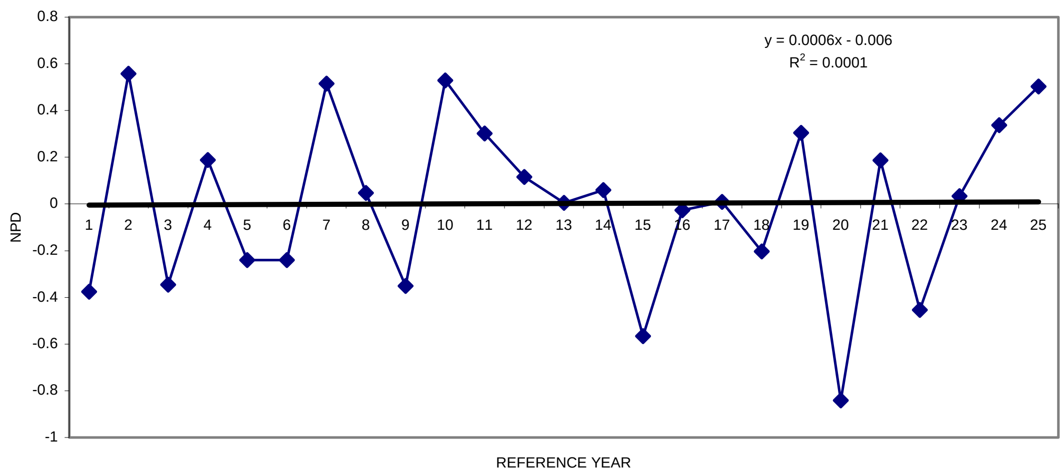
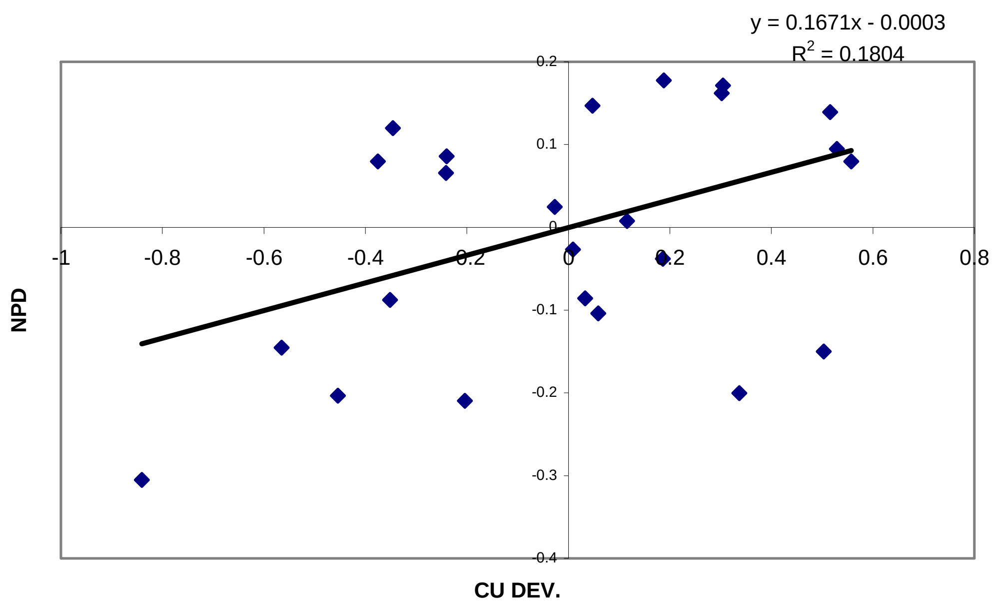



**Fig.16 Senstivity of NPD to chil unit deviation in Himachal Pradesh**




**Special case study of Regional Horticultural Research Station Mashobra**

Relationship of apple productivity \ NPD with reference year (Table 6, fig. 17-19) with respect to RHRS, Mashobra indicates that the productivity of the research farm is declining. The graph between chill unit deviation with NPD shows that apple production change @ of 0.1398/ chill unit and the value for the regression coefficient ($R^2 = 0.1807$)

**Table 6:** Changes in apple production (t/ha) potential of optimally managed orchard and chill unit accumulation at Regional horticultural research station Mashobra (2286 masl) during 1990-91 to 2004-05.

| Production Year | Ref. Year | Yield potential | Trend Predicted Yield | N.Y.D. | Total C.U. | C.U. Deviation |
|---|---|---|---|---|---|---|
| 1990-91 | 1 | 28.76 | 17.449 | 0.6482 | 2214 | 0.1634 |
| 1991-92 | 2 | 12.24 | 17.436 | -0.2980 | 1854 | -0.0257 |
| 1992-93 | 3 | 20.40 | 17.436 | 0.1493 | 2208 | 0.1603 |
| 1993-94 | 4 | 8.36 | 17.431 | -0.5204 | 2106 | 0.1067 |
| 1994-95 | 5 | 14.89 | 17.428 | -0.1456 | 1794 | -0.0573 |
| 1995-96 | 6 | 28.97 | 17.425 | 0.6626 | 2214 | 0.1634 |
| 1996-97 | 7 | 16.52 | 17.422 | -0.0518 | 2010 | 0.0562 |
| 1997-98 | 8 | 13.67 | 17.420 | -0.2153 | 1620 | -0.1487 |
| 1998-99 | 9 | 20.0 | 17.417 | 0.1483 | 2466 | 0.2958 |
| 1999-2000 | 10 | 0.41 | 17.414 | -0.9765 | 1346 | -0.2927 |
| 2000-01 | 11 | 19.18 | 17.411 | 0.1016 | 1944 | 0.0215 |
| 2001-02 | 12 | 5.71 | 17.409 | -0.6720 | 1764 | -0.0730 |
| 2002-03 | 13 | 25.7 | 17.406 | 0.4765 | 1794 | -0.0573 |
| 2003-04 | 14 | 26.72 | 17.403 | 0.5354 | 1548 | -0.1865 |
| 2004-05 | 15 | 19.79 | 17.400 | 0.1374 | 1662 | -0.1266 |

**Fig. 17 Apple productivity trend of Regional horticultural research station Mashobra, Shimla (H.P.)**

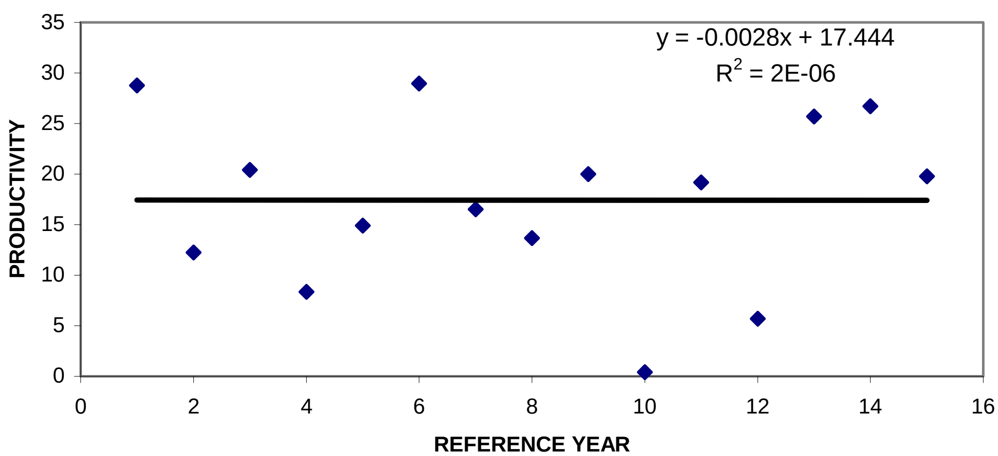


**Fig.18 Normalised productivity deviation trends of apple production in Mashobra (H.P.)**

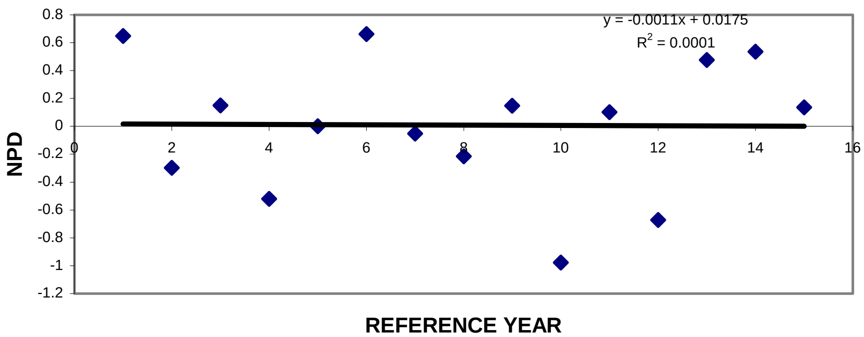
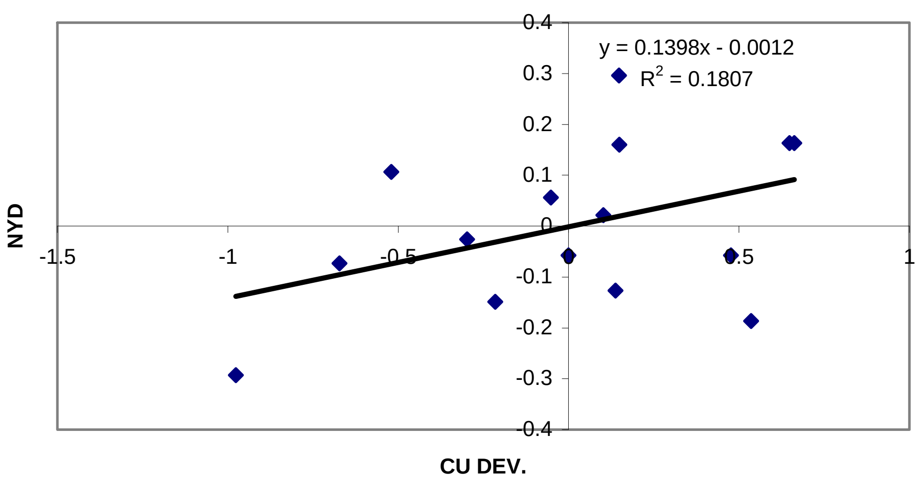



**Fig.19 Senstivity of NPD to chil unit deviation in Mashobra of (H.P.)**



**Objective: Adaptability of apple crop to weather trends and adaptation strategies by the growers.**

**To study the impact of climate change on vulnerability and adaptability of agriculture, horticulture and forest resources in Wet temperate zone of Himachal Pradesh.**

**Methodology**

Increasing temperature in the Himalayan region is adversely affecting the chilling requirement (Fig 34 & 35) of the temperate fruit tree, particularly apple planted in the low lying valley areas. A farmer response based survey was carried out in two major apple growing regions of the Himachal Pradesh to know the farmer's perception about the climate change, vulnerability and adaptability response. For conducting this study two sites were selected in Shimla and Kullu district of Himachal Pradesh each. Both these districts fall under the transition zone between Lesser to Greater Himalayas. The sites selected in Kullu district were Bajaura to Kothi (Rohtang pass, site-I) and Balichowki to Shoza (Jalori jot, site-II). The main characteristic of Bajaura to Kothi valley is that it is broad flat valley, inhabited by rich and influential people, who have got assess to technology. The second site i.e. Balichowki to Shoza (Jalori jot, site-II) is narrow valley, inhabited by people who in comparison to first site is less innovative. Whereas, in Shimla district the sites selected were Rohru to Sungri (site-I) and Chirgaon to Larot (site-II). The people of Rohru and Sungri (site- I) are more prosperous than the Chirgaon to Larot area (site-II). Each site was divided into three elevation ranges (low, middle and high) to know the effect of decreasing temperature/ increasing chilling hours on the mountain farming systems. At each sampling point at least 10 learned farmers/ orchardists were selected to know their perception about the climatic changes and its consequences on mountain farming systems. The majority view emerging out from the present survey is depicted in the table 7-18.

**Results:**

**(A.) Farmer's perception about climate change and its consequences in Kullu district (Himachal Pradesh).**

**(a) Bajaura-Kothi (along Kullu-Manali altitudinal gradient)**

Table 7 reveals the farmers perception about the climatic attributes viz., maximum and minimum temperature, rainfall, snowfall, and hailstorm and frost incidence. Surveys revealed that majority of the farmers were of the view that the maximum temperature has increased at all the three elevation ranges. Whereas, minimum temperature has declined slightly in the lowermost elevation range (1100m). The rainfall has declined and become erratic, irrespective of the elevation ranges. Similarly, snowfall has disappeared from the lowermost elevation range and declined considerably at the middle and higher elevation ranges.

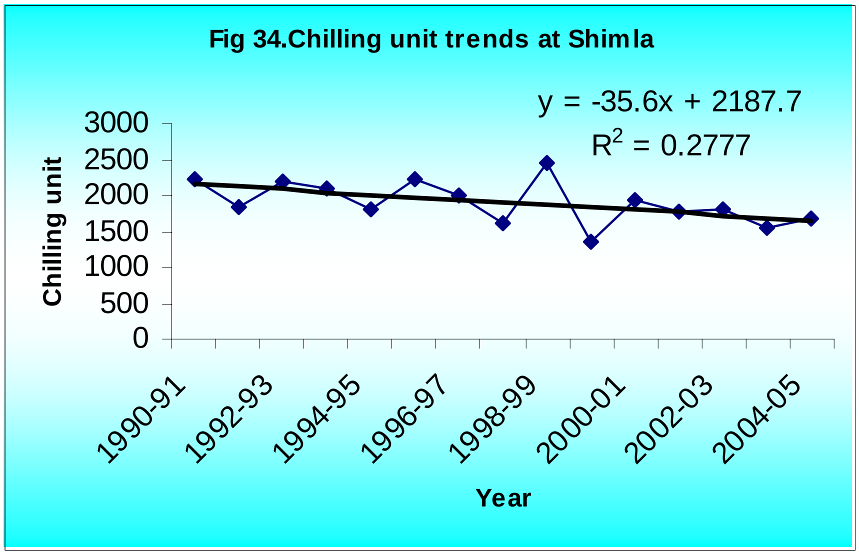


Fig 34.Chilling unit trends at Shimla
y = -35.6x + 2187.7
R2 = 0.2777
Chilling unit
3000
2500
2000
1500
1000
500
0
1990-91
1992-93
1994-95
1996-97
1998-99
2000-01
2002-03
2004-05
Year

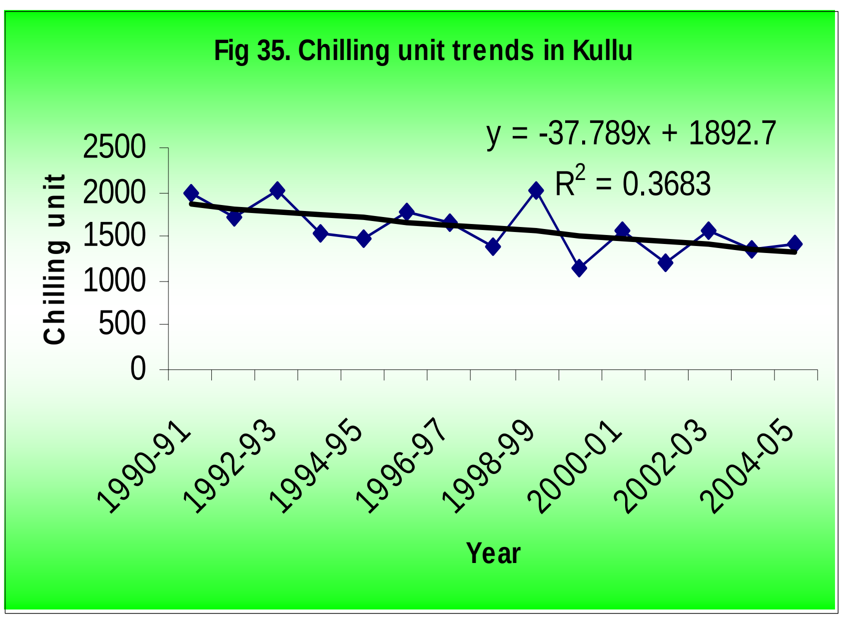


Fig 35. Chilling unit trends in Kullu
y = -37.789x + 1892.7
R2 = 0.3683
Chilling unit
2500
2000
1500
1000
500
0
1990-91
1992-93
1994-95
1996-97
1998-99
2000-01
2002-03
2004-05
Year

**Table 7: Climate change response at different elevation range (Bajaura- Kothi, Kullu district).**

| Climatic parameter | Altitude range | | |
|---|---|---|---|
| | Low (1100 m) | Mid (1800-2000 m) | High (2600-2700) |
| Maximum temperature | Increased | Increased | Increased |
| Minimum temperature | Slight decrease is there | - | - |
| Rainfall | Declined | Erratic | Declined |
| Snowfall | Very less or almost disappeared | Declined considerably ) | Snowfall has declined from 6-7 feet to 2-3 feet, some times it is occurring at flowering time |
| Hailstorm | - | - | - |
| Frost incidence | Increased | - | - |

Survey revealed that because of the climatic changes various forest, fruit and agricultural crops viz., Robinia (*Robinia pseudoacacia),* Deodar *(Cedrus deodara)*, apple (Royal delicious cultivars), plum, apricot (cultivated as well as wild), almond and traditional coarse grain crops, mash and desi palak has become vulnerable because of the changing climatic conditions in the lower valley areas (1100m). At the mid elevation range (1800-2000m) deodar, plum and apple to little extent has become vulnerable. Whereas, at higher elevation ranges (2600-2700 m) there is no threat to any of the mountain farming system component (Table 8).
Because of the decreasing chilling hour at lower elevation range (1100 m), the productivity of high chilling requiring cultivars of apple- (Royal delicious) the orchardists has shifted to low chilling cultivars like Tydeman's early, Coop-12 and Snowmit, and to vegetable and other horticultural crops like cauliflower, cabbage, peas, pomegranate and kiwi, etc (Table 9).
Majority of the framer's at the lower elevation range are of the view that this shift is beneficial to them. Similarly, at the middle altitudinal range the orchardist have also started making suitable varietals and crop changes in response to changing climatic conditions. In contrast to low and middle elevation ranges, where the orchardists are shifting from the apple to other horticultural crop, the farmer at higher elevation ranges are switching from traditional agricultural crop to the apple cultivation, which is proving out to be more beneficial.

**Table 8: Vulnerability response at different elevation range (Bajaura- Kothi, Kullu district).**

| Component | Altitude range | | |
|---|---|---|---|
| | Low (1100 m) | Mid (1800-2000 m) | High (2600-2700) |
| Forest Trees | Robinia and Deodar | Deodar | - |
| Fruit trees | Apple cultivar, plum, apricot (cultivated as well wild) and almond has declined but pear performing well | Plum and apple to little extent also | - |
| Vegetable crop | Local / traditional crop and desi palak have declined | - | - |
| Agricultural crop | Traditional crop like coarse grain and mash | - | - |

**Table 9: Adaptability response at different elevation range (Bajaura- Kothi, Kullu district).**

| Component | Altitude range | | |
|---|---|---|---|
| | Low (1100 m) | Mid (1800-2000 m) | High (2600-2700) |
| Crop change | People have shifted to vegetable crops- Cauliflower, cabbage and peas | People are shifting from apple toward pomegranate and Kiwi and vegetable cultivation | From traditional crop to apple |
| Land use change | On road side only | Fruit crop to vegetable cultivation | yes |
| Varietal change | Some people are shifting to Low chilling cultivars like- Tydeman's, Coop-12, Snowmit | People are adopting low chilling cultivar like- red chief, red spur, scarlet gala | no |
| Sector change | Yes to little extent | Yes to little extent | Shift is there toward tourism |
| Whether the change beneficial or Harmful | Majority response is beneficial | Beneficial | Mixed response. Beneficial for apple production but different from Tourism point of view |

**(b) Balichowki to Shoza (Jalori jot, site-II) altitudinal gradient.**

Farmer's response about the climate change in this valley reveals (Table 10) that the maximum as well as minimum temperature in this valley has increased at all the altitudinal point, with the exception of minimum temperature in the lower most elevation range, where it has become erratic. The precipitation (rainfall as well as snowfall) has declined considerably, irrespective of altitudinal gradient. The elevation range of 2600-2700 m, which earlier (about 40 years ago) receives snowfall of about 10 feet, now receives only about1-2 feet, only. Hailstorm has become common in April (at the flowering time of apple).

**Table 10: Climate change response at different elevation range (Bali chowki, Mandi - Shoza, Kullu district).**

| Climatic parameter | Altitude range | | |
|---|---|---|---|
| | Low (1185 m) | Mid (1400-1600 m) | High (2600-2700) |
| Maximum temperature | Increased | Increased | Increased |
| Minimum temperature | Erratic | Increased | Increased |
| Rainfall | Declined | Declined | Declined |
| Snowfall | Negligible now | Distinctly declined | Snowfall has declined from 10 feet about 40 years back but now about 1 feet only, some times it is occurring at flowering time |
| Hailstorm | More or less same | rare | Hailstorm in April now |
| Frost incidence | Increased | less | - |

Along this altitudinal gradient *Robinia pseudoacacia* and Deodar trees are drying at 1185-1200m elevation range. The area earlier (about 15-20 years ago) produces the bumper crop of apple but now it has totally vanished. The people have shifted to vegetable crop but these are also suffering because of erratic rainfall pattern. Winter season crops are more vulnerable in comparision to kharif season crops. At the middle elevation range, the production of apple is affected but the vegetable production is increasing, which is proving out to be more beneficial. At the highest elevation range the regeneration of Yew (*Taxus baccata)* and Kharsu (*Quercus semecarpifolia*) is on the decline (Table 11).

**Table 11: Vulnerability response at different elevation range (Bali chowki, Mandi - Shoza, Kullu district).**

| Component | Altitude range | | |
|---|---|---|---|
| | Low (1185 m) | Mid (1400-1600 m) | High (2600-2700) |
| Forest Trees | Robinia and Deodar are dying | Kail and Deodar are dying (yellowish ness) | No natural regeneration in Taxus, Kharsu oak |
| Fruit trees | Apple (earlier there use to be bumper crop of apple now no yield) | Apple and wild apricot is dying due to canker | No |
| Vegetable crop | Pea production is affected due drought in winter season | Production is increasing now | People are adopting vegetable crop like-garlic in big way |
| Agricultural crop | Winter season crops are affected only | No effect | Wheat , jow production is declining |

**Table 12: Adaptability response at different elevation range (Bali Chowki, Mandi – Shoza in Kullu District)**

| Component | Altitude range | | |
|---|---|---|---|
| | Low (1700-1800m) | Mid (2100-2300m) | High (2500m) |
| Crop change | Apple to vegetable crops | People are shifting from apple towards vegetable cultivation | From traditional crop to apple & vegetable crops |
| Landuse change | Fruit crops to vegetable cultivation | Fruit crops to vegetable cultivation | Agriculture to Horticulture |
| Varietal change | No | No | No |
| Sector change | - | - | Shift is there toward tourism |
| Whether the change beneficial or harmful | Very harmful | Mixed response | beneficial |

The adaptability response of this valley as presented in the Table (12) reveals that people has shifted from apple to vegetable crop likes peas, cauliflower, carrot and turnip, but the change is not beneficial because of lake of irrigational development. Similar to lower elevation range, farmers in the middle elevation range have also shifted from apple to vegetable cultivation and the response is mixed. At the highest elevation range (2600-2700 m) of this valley, the farmers have shifted from traditional agricultural crop to apple and vegetable crops like garlic and this shift is highly beneficial. In this area the people are now taking two crops in year in comparison to earlier times when only one crop was taken. This area is one of the best examples depicting the beneficial effect of climate change on the people economy.

## (B) Farmer's perception about climate change and its consequences in Shimla district (Himachal Pradesh).

### (a) Rohru-Sungri (along an altitudinal gradient)

Table (13) depicts that farmers perceive that both maximum and minimum temperature has increased at all the elevation ranges along this gradient. The rainfall has become erratic at lower most elevation range (1500-1600 m) and declined considerably at the middle and higher altitude. Similarly, the snowfall has fallen a lot, irrespective of the altitudinal range. At higher altitude (2,300-2,400 m) the hailstorm has become common during the flowering season.
In forest trees, deodar and kail trees has shown decline at low (1500-1600 m) and mid altitude (1700-1800 m) (Table 14). In fruit trees, apple production has declined significantly at lower altitude but at mid altitude there is only a slight reduction. There is no adverse effect on the apple productivity at higher altitude and it has now become more stable. In vegetable crops the sowing and harvesting time of the potato and cauliflower is affected at the lower most elevation range. At the higher elevation ranges the farmers are of the view that the potato production is on the decline probably due to climatic aberrations. In agricultural crops the winter season crops at the lower altitude and pulse production at higher altitude is on the decline.

**Table 13: Climate change response at different elevation (Rohru –Sungri in Shimla district).**

| Climatic parameter | Altitude range | | |
|---|---|---|---|
| | Low (1500-1600 m) | Mid (1700-1800 m) | High (2300-2400 m) |
| Maximum temperature | Increased | Increased | Increased |
| Minimum temperature | Increased | Increased | Increased |
| Rainfall | Erratic | Declined | Declined |
| Snowfall | Declined | Distinctly declined | Snowfall has declined from 10 feet about 40 years back but now about 1 feet only, some times it is occurring at flowering time |
| Hailstorm | More or less same | rare | Hailstorm in April now |
| Frost incidence | less | - | - |

Adaptability response of the farmers of the Rohru to Sungri altitudinal range is presented in the Table 15. The table reveals that People in the lower valley areas have shifted from high chilling requiring apple cultivars (Royal Delicious cultivars) to lower chilling cultivars viz., Vance delicious and Red chief. Some farmers have also started to raise the vegetable crop also. At the middle and higher altitude ranges of this valley, the farmers have converted their agricultural field into apple and potato field. This change has proved to be beneficial, at both the elevation ranges.

**Table 14: Vulnerability response at different elevation range (Rohru –Sungri in Shimla district).**

| Component | Altitude range | | |
|---|---|---|---|
| | Low (1500-1600 m) | Mid (1700-1800 m) | High (2300-2400 m) |
| Forest Trees | Deodar are drying | Kail are Deodar are dying (yellowish ness) | - |
| Fruit trees | Apple. | Apple production slight decline only | No |
| Vegetable crop | Potato and cauliflower (time of sowing and harvesting has changed) | Potato | Potato |
| Agricultural crop | Winter season crops are affected only. Kharif season production is on the rise | Decline in pulse production | Pulse production on decline |

**Table 15: Adaptability response at different elevation range (Rohru – Sungri in Shimla District)**

| Component | Altitude range | | |
|---|---|---|---|
| | Low (1700-1800m) | Mid (2100-2300m) | High (2500m) |
| Crop change | Slight change from apple to vegetables | People are shifting from agriculture to apple & potato in totality | Agriculture crop to apple and potato cultivation |
| Landuse change | No | Agriculture to fruit crops to potato | Agriculture to horticulture |
| Varietal change | From Royal delicious cultivars to Vance Delicious, and red chief. | No | - |
| Sector change | Yes to little extent | No | - |
| Whether the change beneficial or harmful | Mixed response | Beneficial | Beneficial |

**(b) Chirgaon – larot (along an altitudinal gradient)**

A farmer based response survey carried along Chirgaon-Larot altitudinal gradient, having a elevation range of 1700-2500 m reveals that maximum temperature has increased, irrespective of the elevation. Whereas, minimum temperature has remained normal. Rabi season rainfall has declined and has become erratic at all the altitude. Similarly, snowfall has also shown declining trends at all the elevation ranges. The incidence of hailstorm has increased at all the location and it has now started taking place during May-June i.e. the fruiting time of apple crop (Table 16).

**Table 16: Climate change response at different elevation (Chirgaon–Larot in Shimla district**

| Climatic parameter | Altitude range | | |
|---|---|---|---|
| | Low (1700-1800 m) | Mid (2100-2300 m) | High (2500m) |
| Maximum temperature | Increased | Increased | Increased |
| Minimum temperature | normal | normal | normal |
| Rainfall | Erratic, Rabi season rainfall declined | Erratic, Rabi season rainfall declined | erratic |
| Snowfall | Declined drastically | Distinctly declined | Snowfall has declined considerably |
| Hailstorm | Increased considerably | slight | Has started taking place now during May-June. |
| Frost incidence | little | less | |

Vulnerability survey revealed that Deodar at lower altitude, Kail, Kharsu Oak and Deodar at mid and Kharsu at higher altitude range has become vulnerable. A slight decline in apple productivity was there at lower most elevation range. There is no effect on vegetable production at lower and middle altitude. But, at higher elevation a slight reduction in productivity was observed at higher elevation range (Table 17).

**Table 17: Vulnerability response at different elevation range (Chirgaon–Larot in Shimla district).**

| Component | Altitude range | | |
|---|---|---|---|
| | Low (1700-1800 m) | Mid (2100-2300 m) | High (2500m) |
| Forest Trees | Deodar are drying due to moisture stress | Kail, Kharsu and Deodar are dying (yellowish ness) | Insect attack in Oak |
| Fruit trees | Apple but to little extent | - | - |
| Vegetable crop | - | | Potato slight reduction |
| Agricultural crop | Wheat and pulse production has declined | Pulse production on decline | Pulse production on decline |

Adaptability response carried out at three elevation ranges reveals that farmers in this area are shifting from agricultural crop to apple and potato cultivation in totality. This change is proving to be beneficial to the people. Here, it is pertinent to mention that this area is now producing apple of very high quality. Big industrial houses like Reliance and Adani group has established their procurement unit in the orchard itself. Increase in temperature, particularly at the area above 2500 m altitude has made the cultivation of Apple and potato suitable for this height range, which was not possible about 15-20 years ago. And it, has thoroughly transformed the economy of the poor people (Table 18).

**Table 18:** Adaptability response at different elevation range (Chirgaon–Larot in Shimla District)

| Component | Altitude range | | |
|---|---|---|---|
| | Low (1700-1800m) | Mid (2100-2300m) | High (2500m) |
| Crop change | Wheat & rice to apple | People are shifting from agriculture to apple & potato totally | Agriculture crop to apple and potato cultivation |
| Landuse change | Agriculture to horticulture | Agriculture to fruit crops and potato | Agriculture to horticulture |
| Varietal change | No | No | - |
| Sector change | No | No | No |
| Whether the change beneficial or harmful | Mixed response | Beneficial | Beneficial |

**Objective: Carbon sequestration potential of agroforestry systems in different climate types and management regimes.**

**Impact of climate on carbon sequestration potential of agroforestry landuse systems across the altitudinal gradient in Himachal Pradesh Himalayas**

Himachal Pradesh is a mountain locked state and represents four distinct climate types on the basis of altitude, temperature and rainfall. As climate will have overriding effect on agroforestry landuse in a particular region, functional units involved and management adopted; their biomass carbon as well as soil carbon stocks will also vary. Besides, climate also influences the major soil taxonomic groups to some degree and ultimately the total carbon sequestration potential of an agroforestry system. Therefore, aboveground biomass and soil carbon stocks as well as variations therein were studied along the altitudinal gradient covering all the four climate types of Himachal Pradesh. The altitude covered varied from 468m to 2100 m above mean sea level.

**Methodology:**

Four representative sites one in each climate type representing the average climatic conditions of the region were selected. Locality factors of the sites are given in Table 19.

**Table 19.** Locality factors of the study sites**.**

| Sites / Particular | Dhaulakuan | Nauni | Chamba | Kinnaur |
|---|---|---|---|---|
| Latitude | 30° 29’ N | 30°51’ N | 32° 33’ N | 31° 31’ N |
| Longitude | 77° 31’ E | 76° 11’ E | 76° 07’ E | 76° 15’ E |
| Altitude m asl | 468 | 1250 | 2000 | 2100 |
| Climate type | Sub tropical | Sub temperate | Wet temperate | Dry temperate |
| MAT $^{0}$C | 19.50 | 22.35 | 16.07 | 15.33 |
| MAP mm | 1900 | 1085 | 1535 | 4870 |
| Major soil groups | Entisols | Inceptisols | Alfisols | Mollisols |

Agroforestry system types viz agri-silviculture (AS), agri-horticulture (AH), agri-horti-silviculture (AHS) and silvi-pastoral (SP) were chosen at each site. The aboveground biomass of trees, crops, grasses and surface litter was determined for each system. Tree biomass of different plant parts viz., stem, branch and leaf was estimated by non-destructive method employing allometric relationships. In certain case, volume and specific gravity were used to estimate the dry matter accumulation in a tree. The sum of stem + branch + leaf biomass formed the total biomass. The wood biomass was converted into carbon on multiplying by a factor 0.45. Crop and grass biomass was estimated using 1m x 1m quadrate. All the plants occurring within the borders of quadrate were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65°C ± 5° C to a constant weight. The crop and grass biomass was converted into carbon by multiplying with a factor of 0.45. Surface litter was collected from within a centrally placed quadrate 50 cm x 50 cm. Samples were weighted, sub sampled and oven dried at 65± 5° C to a constant weight, ground and ashed. Ash corrected dry weight was assumed to contain 45 % of carbon.

**Results:** The results on aboveground biomass and carbon stocks in different agroforestry systems have been discussed below, systemwise:

**Agri- silviculture (AS)**

Aboveground biomass and total carbon stocks in agri-silviculture system (Table- 20a & 20b) occurring in four climate types were higher in subtropical climate at an altitude of 486 m asl. The functional units of the system were Toona + Maize – Wheat. The same system type with different functional units (Quercus + Maize- Wheat) in wet temperate climate at an altitude of 2000 m asl had the lowest carbon stocks. Poplar based agri-silviculture system present – both in dry-temperate 2100 m asl and subtropical climates had higher aboveground biomass and stored carbon (66.36 Mg/ ha and 29.86 Mg/ha, respectively) in dry temperate climate

**Agri- horticulture (AH)**

The maximum total biomass (74.48 Mg / ha) and carbon stocks (33.52 Mg/ha) were found in apple based system (Apple +Pea) in dry temperate climate. Apple + Cabbage-Frenchbean based system in sub-temperate climate type had the second highest value which produced 60.40 Mg/ha of aboveground biomass and 27.18 Mg/ha of stored carbon. AH system (Peach + Soybean - Wheat) in sub–temperate region produced lowest aboveground biomass (29.10 Mg/ha) and carbon stock (13.09 Mg/ha) (Table 21a &b). The results indicated that apple based AH system in temperate dry climate and sub-temperate climate had higher carbon stocks than peach based AH system in sub-temperate climate.

**Agri- horti- silviculture (AHS)**

Agri-horti-silviculture system was prominent in sub-tropical and sub-temperate climates, only. In sub-tropical climate three AHS units were prominent viz., Mango + Poplar + Paddy – Wheat, Mango + Grewia + Paddy – Wheat and Mango + Toona + Maize - Wheat. Among these combinations, Mango + Toona + Maize - Wheat produced the maximum biomass (154.92 Mg/ha) and the resultant carbon (69.71 Mg/ha) stocks.

In sub-temperate climate two tree-crop combinations viz. Plum + Morus+ Soybean- Wheat and Peach + Grewia + Soybean – Wheat were prominent. Later combination sequestered more carbon than the former. In general, AHS system in sub-tropical climate showed higher carbon sequestration potential in terms of studied carbon stock.

**Silvi-pastoral (SP)**

Silvi-pastoral system in each climate type had more than one unit owing to the dominance of a particular woody species. In subtropical climate the maximum biomass (68.70 Mg/ha) and carbon stocks (30.91 Mg/ha) were in *Acacia catechu* based silvi-pastoral system. On the other hand sub-temperate climate *Pinus roxburghii* based system gave the highest value for aboveground biomass (255.69 Mg/ha) and carbon stock (115.06 Mg/ha). In wet temperate zone, among the Quercus and Robinia based systems the higher total above ground biomass (97.04 Mg/ha) and carbon stock (43.66 Mg/ha) were in Quercus based system. In dry temperate zone Salix based SP system produced the higher amount of total aboveground biomass (161.65 Mg/ha) along with carbon stock (72.74 Mg/ha). The above results thus indicated that *Pinus roxburghii*: based silvi-pasture system had the highest carbon sequestration potential- over all other combinations prevalent in different in different climate types. In dry temperate and wet temperate climates Salix and Quercus based SP systems are most potential.

**Carbon sequestration potential accumulation rates of different agroforestry systems**

Climate type besides influencing the functional units of an agroforestry system type also affect their carbon sequestration potential or carbon accumulation rates. Data in Fig- 36 showed that Agri- silviculture (AS) system had the highest carbon accumulation rate (and silvi- pasture system the minimum in subtropical climate. All the three agroforestry systems viz. AS, AH and SP had higher accumulation rate in sub-tropical climate and the least in dry temperate. Overall subtropical climate with an average carbon accumulation rate of 5.85 Mg ha $^{-1}$yr$^{-1}$ showed the maximum carbon sequestration potential irrespective of Agroforestry system type whereas, the dry temperate the minimum. Among the agroforestry systems types maximum CS potential was shown by AS system (7.37 Mg ha $^{-1}$yr$^{-1}$) and SP the minimum (2.07 Mg ha $^{-1}$yr$^{-1}$) irrespective of climate type.

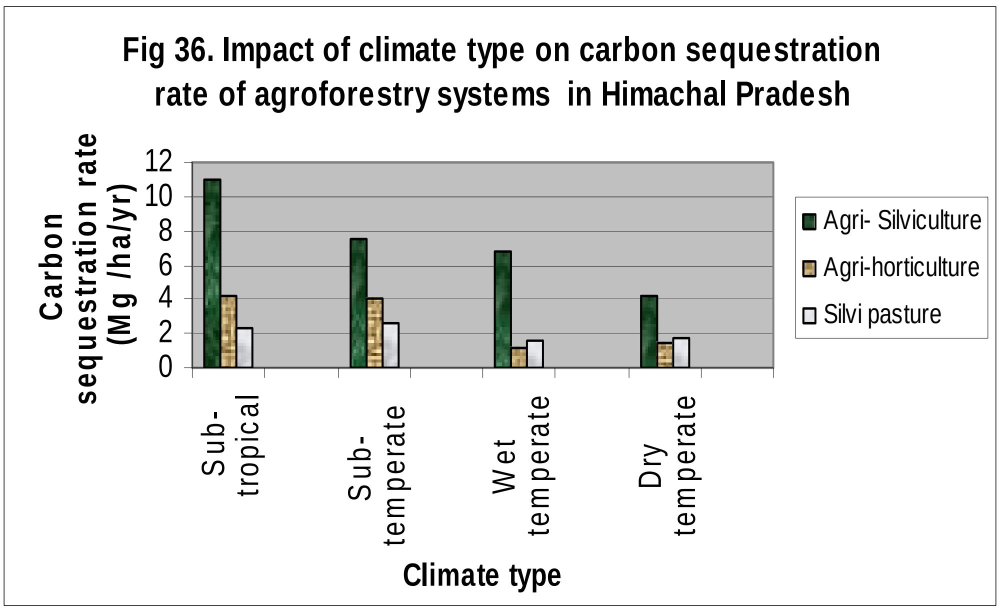


**Table 20a. Aboveground biomass levels (Mg/ha) of agri-silviculture (AS) system influenced by altitudinal gradient or climate type.**

| Climate type | Altitude (m asl) | Functional units | Tree density (stems ha$^{-1}$) | Biomass | | | |
|---|---|---|---|---|---|---|---|
| | | | | Tree | Crop | Litter | Total |
| **Sub-tropical** | 468 | Poplar + Paddy- Wheat | 200 | 11.66 | 14.62 | 1.05 | 27.27 |
| | | Toona + Maize – Wheat | 200 | 460.64 | 19.56 | 14.41 | 494.61 |
| **Sub-temperate** | 1250 | Grewia + Soybean – Wheat | 200 | 33.2 | 8.79 | 0.66 | 42.65 |
| **Wet – temperate** | 2000 | Quercus + Maize -Wheat | 44 | 14.65 | 8.08 | 3.22 | 25.95 |
| **Dry – temperate** | 2100 | Poplar + Barley | 170 | 57.98 | 7.10 | 1.28 | 66.36 |

**Table 20b. Aboveground carbon stocks (Mg/ha) of agri-silviculture (AS) system influenced by altitudinal gradient or climate type .**

| Climate type | Altitude (m asl) | Functional units | Tree density (stems ha$^{-1}$) | Carbon stocks | | | |
|---|---|---|---|---|---|---|---|
| | | | | Tree | Crop | Litter | Total |
| **Sub-tropical** | 468 | Poplar + Paddy- Wheat | 200 | 5.24 | 6.57 | 0.47 | 12.27 |
| | | Toona + Maize – Wheat | 200 | 207.28 | 8.80 | 6.48 | 222.57 |
| **Sub-temperate** | 1250 | Grewia + Soybean – Wheat | 200 | 14.94 | 3.95 | 0.29 | 19.19 |
| **Wet – temperate** | 2000 | Quercus + Maize - Wheat | 44 | 6.59 | 3.63 | 1.449 | 11.67 |
| **Dry – temperate** | 2100 | Poplar + Barley | 170 | 26.09 | 3.19 | 0.57 | |

**Table 21a. Aboveground biomass levels (Mg/ha) of agri- horticulture (AH) system influenced by altitudinal gradient or climate type.**

| Climate type | Altitude (m asl) | Functional units | Tree density (stems $ha^{-1}$) | Biomass | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Tree | Pruned wood | Crop | Litter | Fruit yield | Total |
| **Sub-tropical** | 468 | Mango + Paddy - Wheat | 100 | 15.82 | - | 11.19 | 2.25 | 14.56 | 43.82 |
| **Sub-temperate** | 1250 | Peach +Soybean - Wheat | 200 | 12.42 | 0.6 | 8.32 | 1.42 | 6.34 | 29.10 |
| | | Apple + Cabbage- French bean | 185 | 29.24 | 2.22 | 17.78 | 1.16 | 10.00 | 60.40 |
| **Wet – temperate** | 2000 | Apple + Potato | 250 | 17.95 | 3.25 | 2.00 | 0.97 | 25.00 | 49.17 |
| **Dry – temperate** | 2100 | Apple + Pea | 250 | 39.53 | 4.80 | 3.10 | 1.99 | 25.06 | 74.48 |

**Table 21b. Aboveground carbon stocks (Mg/ha) of agri- horticulture (AH) system influenced by altitudinal gradient or climate type.**

| Climate type | Altitude (m asl) | Functional units | Tree density (stems $ha^{-1}$) | Carbon stocks | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Tree | Pruned wood | Crop | Litter | Fruit yield | Total |
| **Sub-tropical** | 468 | Mango + Paddy - Wheat | 100 | 7.12 | - | 5.04 | 1.01 | 6.55 | 19.72 |
| **Sub-temperate** | 1250 | Peach +Soybean - Wheat | 200 | 5.59 | 0.27 | 3.74 | 0.64 | 2.85 | 13.09 |
| | | Apple + Cabbage- Frenchbean | 185 | 13.16 | 0.99 | 8.00 | 0.52 | 4.50 | 27.18 |
| **Wet – temperate** | 2000 | Apple + Potato | 250 | 8.08 | 1.46 | 0.90 | 0.44 | 11.25 | 22.13 |
| **Dry – temperate** | 2100 | Apple + Pea | 250 | 17.78 | 2.16 | 1.39 | 0.89 | 11.28 | 33.52 |

**Table 22a. Aboveground biomass levels (Mg/ha) of agri- horti-silviculture (AHS) system influenced by altitudinal gradient or climate type.**

| Climate type | Altitude (m asl) | Functional units | Tree density (stems $ha^{-1}$) | Biomass | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Tree | Pruned wood | Crop | Litter | Fruit yield | Total |
| **Sub-tropical** | 468 | Mango + Poplar + Paddy - Wheat | 200 | 17.15 | - | 4.43 | 0.72 | 12.2 | 34.5 |
| | | Mango + Grewia + Paddy – Wheat | 200 | 29.98 | - | 4.03 | 1.16 | 18.50 | 53.67 |
| | | Mango + Toona + Maize - Wheat | 200 | 132.13 | - | 4.84 | 1.73 | 16.22 | 154.92 |
| **Sub-temperate** | 1250 | Plum + Morus+ Soybean - Wheat | 332 | 7.84 | 1.33 | 4.06 | 0.65 | 8.16 | 22.04 |
| | | Peach + Grewia + Soybean-Wheat | 332 | 7.86 | 2.01 | 4.06 | 0.35 | 10.30 | 24.58 |
| **Wet – temperate** | 2000 | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ |
| **Dry – temperate** | 2100 | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ |

**¥: System type was not predominant in the particular climate type**

**Table 22b. Aboveground carbon socks (Mg/ha) of agri- horti-silviculture (AHS) system influenced by altitudinal gradient or climate type.**

| Climate type | Altitude (m asl) | Functional units | Tree density (stems ha$^{-1}$) | Carbon stocks | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Tree | Pruned wood | Crop | Litter | Fruit yield | Total |
| **Sub-tropical** | 468 | Mango + Poplar + Paddy - Wheat | 200 | 7.71 | - | 1.99 | 0.32 | 5.40 | 15.50 |
| | | Mango + Grewia + Paddy – Wheat | 200 | 13.49 | - | 1.81 | 0.52 | 8.32 | 24.15 |
| | | Mango + Toona + Maize - Wheat | 200 | 59.45 | - | 2.17 | 0.77 | 7.29 | 69.71 |
| **Sub-temperate** | 1250 | Plum + Morus+ Soybean - Wheat | 332 | 31.52 | 0.59 | 1.82 | 0.29 | 3.62 | 16.50 |
| | | Peach + Grewia + Soybean-Wheat | 332 | 3.53 | 0.90 | 1.82 | 0.15 | 4.63 | 11.06 |
| **Wet – temperate** | 2000 | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ |
| **Dry – temperate** | 2100 | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ | ¥ |

**¥: System type was not predominant in the particular climate type**

**Table 23a. Aboveground biomass levels (Mg/ ha) of silvi-pasture (SP) system influenced by altitudinal gradient or climate type.**

| climate type | Altitude (m asl) | Functional units | Tree density (stems ha$^{-1}$) | Biomass | | | |
|---|---|---|---|---|---|---|---|
| | | | | Tree | Grass | Litter | Total |
| **Sub-tropical** | 468 | *Acacia catechu*+ Natural grass | 127 | 61.79 | 4.90 | 2.01 | 68.70 |
| | | *Grewia optiva*+ Natural grass | 127 | 49.52 | 2.31 | 1.55 | 53.38 |
| **Sub-temperate** | 1250 | *Acacia catechu*+ Natural grass | 54 | 16.81 | 5.20 | 0.66 | 22.67 |
| | | *Grewia optiva* + Natural grass | 54 | 22.68 | 4.13 | 0.80 | 27.61 |
| | | Pinus roxburghii + Natural grass | 500 | 246.75 | 1.50 | 7.44 | 255.69 |
| **Wet temperate** | 2000 | Quercus + Natural grass | 150 | 92.30 | 1.91 | 2.83 | 97.04 |
| | | *Robinia pseudocasia*+ Natural grass | 150 | 4.92 | 3.40 | 0.25 | 8.57 |
| **Dry temperate** | 2100 | Salix+ Natural grass | 170 | 157.08 | 2.43 | 2.14 | 161.65 |
| | | *Robinia pseudoacasia*+ Natural grass | 70 | 4.04 | 2.95 | 0.21 | 7.20 |

**Table 23b. Aboveground carbon stocks (Mg/ ha) of silvi-pasture (SP) system influenced by altitudinal gradient or climate type.**

| Climate type | Altitude (m asl) | Functional units | Tree density (stems $ha^{-1}$) | Carbon stocks | | | |
|---|---|---|---|---|---|---|---|
| | | | | Tree | Grass | Litter | Total |
| **Sub-tropical** | 468 | *Acacia catechu*+ Natural grass | 127 | 27.80 | 2.20 | 0.90 | 30.91 |
| | | *Grewia optiva*+ Natural grass | 127 | 22.28 | 1.03 | 0.69 | 24.02 |
| **Sub-temperate** | 1250 | *Acacia catechu*+ Natural grass | 54 | 7.56 | 2.34 | 0.29 | 10.20 |
| | | *Grewia optiva* + Natural grass | 54 | 10.20 | 1.85 | 0.36 | 12.42 |
| | | *Pinus roxburghii* + Natural grass | 500 | 111.03 | 0.67 | 3.34 | 115.06 |
| **Wet temperate** | 2000 | Quercus + Natural grass | 150 | 41.53 | 0.85 | 1.27 | 43.66 |
| | | *Robinia pseudocasia*+ Natural grass | 150 | 2.21 | 1.53 | 0.11 | 3.85 |
| **Dry temperate** | 2100 | Salix + Natural grass | 170 | 70.68 | 1.09 | 0.96 | 72.74 |
| | | *Robinia pseudoacasia*+ Natural grass | 70 | 1.81 | 1.32 | 0.09 | 3.24 |

**Table 24. Impact of climate type on carbon sequestration rate (Mg ha $^{-1}$yr$^{-1}$) of agroforestry systems along the altitudinal gradient (468-2100 m asl in H.P).**

| Climate type | Agroforestry systems | | | Mean |
|---|---|---|---|---|
| | Agri- Silviculture | Agri-horticulture | Silvi-pasture | |
| **Sub-tropical** | 10.99 | 4.19 | 2.37 | 5.85 |
| **Sub-temperate** | 7.48 | 4.09 | 2.55 | 4.71 |
| **Wet temperate** | 6.77 | 1.16 | 1.64 | 3.19 |
| **Dry temperate** | 4.24 | 1.46 | 1.73 | 2.47 |
| **Mean** | 7.37 | 2.73 | 2.07 | |

**Objective: Evaluation and preparation of the carbon inventories of the different agroforest for trading carbon under CDM.**

**Carbon inventory of agroforestry systems of Himachal Pradesh**

**Methodology:**

The state of Himachal Pradesh represents four distinct agroclimatic zone namely sub-tropical sub-montane and low hills, sub-temperate sub-humid mid hills, wet temperate high hills and dry temperate high hills. Predominant agroforestry systems viz. agri-silviculture, agri-horti-silviculture and silvipastoral in each of the four climate types were selected for preparing carbon inventory. The inventory was prepared using the methodology given in the revised 1996 IPCC guidelines for national greenhouse gas inventory. In order to estimate the total biomass accumulation by forest/ fruit tree non- destructive method of biomass estimation was used. In case of forest trees, species specific volume tables were prepared to estimate the biomass. To know the contribution of agroforestry systems towards total / net carbon sequestration annual crop sequence followed was taken as baseline scenario.

**Results**

**A) Agri-silviculture system**

Carbon inventory of agroforestry systems of the state is given in table-25 (A). Agri-silviculture system (AS) had the maximum net annual carbon uptake (5.6Mgha$^{-1}$) in sub-tropical climate, which was about thirteen times higher than the baseline scenario maize+wheat cropping sequence (Table-1A). In dry temperate zone the net annual carbon uptake through agrisilviculture system was though about three times less (1.88 Mgha$^{-1}$) yet its contribution was about two times more in this region than in sub-tropical region. Further, this system has shown its minimum contribution towards sequestering carbon in wet temperate climate type.

**B) Agri-horti-silviculture system**

Agri-horti-silviculture system was a predominant landuse in sub- tropical and sub-temperate climate types. Under the present management, it is likely to enhance the atmospheric carbon pool than to reduce it. The system in sub-tropical climate is likely to release about 12.5 Mg of $CO_2$ per hectare. However the $CO_2$ emission can be reduced to 2.4 Mgha$^{-1}$ by substituting *Grewia optiva* with *Toona ciliata* as functional component. Similarly in sub-temperate climate the system involving Peach+Grewia+Soybean-wheat may emit about 2.6 Mg of $CO_2$ per hectare which can be brought down to 1.8 Mgha$^{-1}$ by using Plum+Morus+soybean-wheat (Table-25 B).

**C) Agri-horticulture system**

Agri-horticulture system is the most commonly used landuse in the hills of Himachal Pradesh under all the climate types but is not climate friendly. Under sub-tropical climate type it is likely to release about 7.9Mgha$^{-1}$ $CO_2$. Whereas, in sub-temperate climate involving apple+cabbage-frenchbean it emitted 0.26 Mgha$^{-1}$ of $CO_2$. Another system unit peach+soybean-wheat of the same system behaved opposite to the above and helped sequestering about 0.55 Mg of $CO_2$ ha$^{-1}$. The agri-horticulture system in the wet-temperate and dry-temperate zone involving apple+potato and apple+Pea was also found releasing carbon dioxide to the atmosphere under the present management. About 2.95 and 3.79 Mg of $CO_2$ per hectare respectively was observed to be emitted by these systems (table-25 C).

**D) Silvi-pastoral system**

In case of silvi-pastoral system (Salix+natural grass) maximum net annual carbon uptake was 3.54 $Mgha^{-1}$ in dry-temperate zone (Table-25 (D)). It was about 118 times more than the baseline scenario of pure natural grassland. In sub-temperate climate the net annual carbon uptake through silvi-pastoral system involving Pine+natural grass was about 1.85 $Mgha^{-1}$ which was about two times less than the it could sequester in dry-temperate climate. The contribution of this system in this climate however was about 26 times more than baseline scenario. The system was observed as having highest carbon sequestering potential under all the four climatic types of Himachal Pradesh.

**Regional climate zonewise carbon sequestration and mitigation dynamics of agroforestry systems of Himachal Pradesh**

**Results:**

Agroforestry systems in different climate types of the state were studied for their contribution towards total carbon sequestered and their likely $CO_2$ mitigation impact in terms of net carbon locked by each system uptill the age when observations were recorded.

**A) Agri-silviculture system**

Agri-silviculture system (Toona+maize-wheat) in sub-tropical climate sequestered about 222.58 $Mgha^{-1}$ of total carbon (Table-26A). The carbon emitted by the system was 8.76 Mg/ha which was little less than baseline scenario of maize-wheat (9.78 $Mgha^{-1}$). The total carbon locked by the system was also maximum (213.77 $Mgha^{-1}$) that showed its capacity to lock about 784 Mg $CO_2$ $ha^{-1}$ which otherwise would have been released to the atmosphere. This system was equally effective (Poplar+barley) in dry-temperate climate. It could lock 97.87 $Mgha^{-1}$ of $CO_2$ equivalent carbon. In wet-temperate climate the system showed the minimum capacity to lock the carbon may be because of the nature of woody species involved as the major functional component. It was also observed that in sub-tropical climate the baseline scenario maize-wheat was the highest total carbon emitter followed by paddy-wheat. Baseline scenario barley in dry-temperate region was the least emitter. The total carbon emission values for these scenarios were: 9.78, 7.31 and 3.20 $Mgha^{-1}$, respectively.

**B) Agri-horti-silviculture system**

Agri-horti-silviculture system in sub-tropical climate enhanced the amount of total C sequestered manifold over the baseline scenario of paddy-wheat and maize-wheat. Maximum (67.9 $Mgha^{-1}$) carbon sequestered was through mango+Toona+maize-wheat agri-horti-silviculture system followed by mango+Grewia+maize-wheat. In sub-temperate climate peach+Grewia+soybean-wheat system showed higher amount of sequestered carbon over plum+Morus+soybean-wheat.
Regards total carbon emission through this system the data in the table-26B revealed that total amount of the carbon emitted during the year of observation was highest (10.14 $Mgha^{-1}$) when

mango+Grewia+paddy-wheat were the functional component of the system. It was followed by mango+Toona+maize-wheat system. However, net carbon locked by these two system units was highest and exhibited the maximum carbon mitigation potential.

### C) Agri-horticulture system

Agri-horticulture system in dry-temperate climate enhanced the total carbon sequestered to the maximum of 33.52 $Mgha^{-1}$ (Table-26C). In sub-temperate climate using apple+cabbage-frenchbean as a functional component the total carbon sequestered was 27.18 $Mgha^{-1}$ by this system. Total carbon emission per hectare during the year was maximum in dry-temperate region followed by wet & sub-temperate climate, when apple was the functional woody component. Despite of high carbon emission, net mitigation impact of the system in terms of the $CO_2$ locked was highest in case of apple based system.

### D) Silvi-pastoral system

Silvi-pastoral system is a common landuse to all the climate types of Himachal Pradesh and has been observed as a most promising among all other agroforestry systems to be adopted for carbon sequestration. Silvi-pastoral system (*Pinus roxburghii* + natural grass) in sub–temperate climate sequestered about 115.06 Mg carbon $ha^{-1}$. The carbon emitted by the system was 0.68 Mg $ha^{-1}$ which was minimum and the net carbon locked (114.39 Mg/ha) was maximum which showed its capacity to lock about 419.79 Mg $CO_2$ per hectare (Table-26D). The system was found to be equally effective (Salix + natural grass) in dry temperate zone. In wet temperate climate system it could lock 42.81 Mg of net carbon per hectare. However, it is not so efficient when *Robinia pseudoacacia* is used as functional component in place of Salix in both the climates that is wet temperate and dry temperate.

**Table 25: Regional climatic zonewise carbon inventory* of agroforestry systems of Himachal Pradesh**

**25A) Agri-silviculture System**

| Climatic type / Landuse system | Area of system (A) | Annual growth rate (Mg/ha) (B) | Annual biomass increment (Mg) (C) | Carbon fraction of the DM (D) | Total carbon Uptake increment (Mg) (E) | Biomass of the system (Mg/ha) (F) | Biomass removed from the system (Mg) (G) | C fraction (H) | Annual C release (Mg) (I)=G*H | Net annual C uptake/release (Mg) (J)=E-I | $CO_2$ annual emission/ removal from the system (Mg) (K)=J*3.67 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sub-tropical** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Paddy-wheat | 10 | 16.74 | 167.4 | .45 | 75.33 | 167.4 | 162.4 | .45 | 73.08 | 2.25 | 8.26 |
| Maize-wheat | 10 | 22.64 | 226.4 | .45 | 101.88 | 226.38 | 217.33 | .45 | 97.80 | 4.08 | 14.98 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Poplar+paddy-wheat | 10 | 15.39 | 153.9 | .45 | 69.26 | 272.7 | 146.2 | .45 | 65.80 | 3.39 | 12.44 |
| Toona+maize-wheat | 10 | 32.04 | 320.4 | .45 | 144.18 | 4946.1 | 195.6 | .45 | 88.00 | 56.18 | 206.18 |
| **Sub-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Soybean-wheat | 10 | 10.06 | 100.6 | .45 | 45.27 | 100.69 | 97.66 | .45 | 43.95 | 1.32 | 4.86 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Grewia+ Soybean-wheat | 10 | 10.66 | 106.60 | .45 | 47.97 | 426.5 | 87.9 | .45 | 39.60 | 8.37 | 30.72 |
| **Wet-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Maize-wheat | 10 | 9.25 | 92.5 | .45 | 41.65 | 92.55 | 89.78 | .45 | 40.40 | 1.25 | 4.58 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Quercus+ maize-wheat | 10 | 8.66 | 86.60 | .45 | 38.97 | 259.5 | 80.8 | .45 | 36.40 | 2.57 | 9.43 |
| **Dry-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Barley | 10 | 8.05 | 80.5 | .45 | 36.23 | 80.50 | 78.89 | .45 | 35.50 | 0.73 | 2.68 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Poplar+barley | 10 | 11.30 | 113.00 | .45 | 50.85 | 663.6 | 71.00 | .45 | 32.00 | 18.85 | 69.18 |

*Inventory based on revised 1996 IPCC guidelines for National Greenhouse Gas Inventory

**25B) Agri-horti-silviculture System**

| Climatic type / Landuse system | Area of system (A) | Annual growth rate (Mg/ha) (B) | Annual biomass increment (Mg) (C) | Carbon fraction of the DM (D) | Total carbon Uptake increment (Mg) (E) | Biomass of the system (Mg/ha) (F) | Biomass removed from the system (Mg) (G) | C fraction (H) | Annual C release (Mg) (I)=G*H | Net annual C uptake/release (Mg) (J)=E-I | $CO_2$ annual emission/ removal from the system (Mg) (K)=J*3.67 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sub-tropical** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Paddy-wheat | 10 | 4.56 | 45.6 | .45 | 20.52 | 45.6 | 44.3 | .45 | 19.9 | 0.62 | 2.27 |
| Maize -wheat | 10 | 4.98 | 49.8 | .45 | 22.41 | 49.8 | 48.4 | .45 | 21.78 | 0.63 | 2.31 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Mango+Poplar+Paddy-wheat | 10 | 11.38 | 113.8 | .45 | 51.21 | 345.0 | 166.3 | .45 | 74.80 | -23.59 | -86.57 |
| Mango+Grewia+Paddy-wheat | 10 | 14.93 | 149.3 | .45 | 67.19 | 536.7 | 225.3 | .45 | 101.39 | -34.20 | -125.51 |
| Mango+Toona+Maize -wheat | 10 | 19.56 | 195.6 | .45 | 88.02 | 1549.2 | 210.6 | .45 | 94.80 | -6.78 | -24.88 |
| **Sub-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Soybean-wheat | 10 | 4.27 | 42.7 | .45 | 19.22 | 42.7 | 40.6 | .45 | 18.27 | 0.95 | 3.49 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Plum+Morus+Soybean -wheat | 10 | 12.61 | 126.1 | .45 | 56.75 | 220.4 | 135.5 | .45 | 61.80 | -5.05 | -18.53 |
| Peach+Grewia+Soybean -wheat | 10 | 14.75 | 147.5 | .45 | 66.36 | 245.8 | 163.7 | .45 | 73.70 | -7.34 | -26.94 |

**25C) Agri-horticulture System**

| Climatic type / Landuse system | Area of system (A) | Annual growth rate (Mg/ha) (B) | Annual biomass increment (Mg) (C) | Carbon fraction of the DM (D) | Total carbon Uptake increment (Mg) (E) | Biomass of the system (Mg/ha) (F) | Biomass removed from the system (Mg) (G) | C fraction (H) | Annual C release (Mg) (I)=G*H | Net annual C uptake/release (Mg) (J)=E-I | $CO_2$ annual emission/ removal from the system (Mg) (K)=J*3.67 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sub-tropical** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Paddy-wheat | 10 | 12.81 | 128.1 | .45 | 57.65 | 128.18 | 124.3 | .45 | 55.94 | 1.72 | 6.29 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Mango+Paddy-wheat | 10 | 13.54 | 135.4 | .45 | 60.93 | 438.2 | 183.5 | .45 | 82.57 | -21.64 | -79.42 |
| **Sub-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Soybean -wheat | 10 | 13.06 | 130.6 | .45 | 58.77 | 130.6 | 126.7 | .45 | 57.02 | 1.75 | 6.42 |
| Cabbage-frenchbean | 10 | 24.75 | 247.5 | .45 | 111.38 | 247.5 | 240.1 | .45 | 108.05 | 3.33 | 12.22 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Peach+Soybean -wheat | 10 | 15.60 | 156.00 | .45 | 70.20 | 291.0 | 152.6 | .45 | 68.70 | 1.50 | 5.51 |
| Apple+cabbage-frenchbean | 10 | 29.84 | 298.4 | .45 | 134.28 | 604.0 | 300.0 | .45 | 135.00 | -0.72 | -2.64 |
| **Wet-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Potato | 10 | 2.38 | 23.8 | .45 | 10.71 | 23.8 | 23.8 | .45 | 10.71 | 0 | 0 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Apple+Potato | 10 | 28.47 | 284.7 | .45 | 128.07 | 491.7 | 302.4 | .45 | 136.10 | -8.03 | -29.47 |
| **Dry-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Pea | 10 | 4.29 | 42.9 | .45 | 19.31 | 42.9 | 40.3 | .45 | 18.14 | 1.17 | 4.29 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Apple+Pea | 10 | 30.66 | 306.60 | .45 | 137.97 | 744.8 | 329.6 | .45 | 148.30 | -10.33 | -37.91 |

**25D) Silvi-pastoral System**

| Climatic type / Landuse system | Area of system (A) | Annual growth rate (Mg/ha) (B) | Annual biomass increment (Mg) C) | Carbon fraction of the DM (D) | Total carbon Uptake increment (Mg) (E) | Biomass of the system (Mg/ha) (F) | Biomass removed from the system (Mg) (G) | C fraction (H) | Annual C release (Mg) (I)=G*H | Net annual C uptake/release (Mg) (J)=E-I | $CO_2$ annual emission/ removal from the system (Mg) (K)=J*3.67 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sub-tropical** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Natural grass | 10 | 6.26 | 62.6 | .45 | 28.17 | 62.6 | 61.3 | .45 | 27.59 | 0.58 | 2.13 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| *Acacia catechu*+Natural grass | 10 | 7.98 | 79.8 | .45 | 35.91 | 687.0 | 49.0 | .45 | 22.1 | 13.81 | 50.68 |
| *Grewia optiva*+ Natural grass | 10 | 4.79 | 47.9 | .45 | 21.56 | 533.8 | 23.1 | .45 | 10.4 | 11.16 | 40.96 |
| **Sub-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Natural grass | 10 | 5.01 | 50.06 | .45 | 22.53 | 50.06 | 48.56 | .45 | 21.85 | 0.68 | 2.49 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| *Acacia catechu* + Natural grass | 10 | 6.32 | 63.2 | .45 | 28.44 | 226.7 | 52.0 | .45 | 23.4 | 5.04 | 18.50 |
| *Grewia optiva*+ Natural grass | 10 | 5.26 | 52.6 | .45 | 23.67 | 276.1 | 41.3 | .45 | 18.6 | 5.07 | 18.61 |
| *Pinus roxburghii*+ Natural grass | 10 | 5.61 | 56.1 | .45 | 25.25 | 2556.9 | 15.0 | .45 | 06.8 | 18.48 | 67.71 |
| **Wet-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Natural grass | 10 | 3.60 | 36.0 | .45 | 16.20 | 36.0 | 35.3 | .45 | 15.88 | 0.32 | 1.16 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Quercus+ | 10 | 3.96 | 39.6 | .45 | 17.82 | 970.4 | 19.1 | .45 | 08.6 | 9.22 | 33.84 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural grass | | | | | | | | | | | |
| Robinia+ Natural grass | 10 | 4.02 | 40.2 | .45 | 18.09 | 85.7 | 34.0 | .45 | 15.3 | 2.79 | 10.24 |
| **Dry-temperate** | | | | | | | | | | | |
| **Baseline scenario** | | | | | | | | | | | |
| Natural grass | 10 | 3.63 | 36.3 | .45 | 16.34 | 36.3 | 35.6 | .45 | 16.02 | 0.32 | 1.16 |
| **Agroforestry system scenario** | | | | | | | | | | | |
| Salix+ Natural grass | 10 | 10.28 | 102.8 | .45 | 46.26 | 1616.5 | 24.3 | .45 | 10.9 | 35.36 | 129.77 |
| Robinia+ Natural grass | 10 | 3.76 | 37.6 | .45 | 16.92 | 72.0 | 29.5 | .45 | 13.3 | 3.62 | 13.29 |

**Table 26: Regional climatic zonewise carbon sequestration and mitigation dynamics of agroforestry systems of Himachal Pradesh**

**26A) Agri-silviculture System**

| Climate type | Functional component | | | Total carbon sequestered (Mg/ha) | *Total carbon emitted (Mg/ha) | Likely $CO_2$ mitigation | |
|---|---|---|---|---|---|---|---|
| | | | | | | **Net carbon locked (Mg/ha) | Net $CO_2$ locked (Mg/ha) |
| Sub-tropical | **Baseline** | **i** | Paddy-wheat | 7.53 | 7.31 | 0.23 | 0.83 |
| | | **ii** | Maize-wheat | 10.19 | 9.78 | 0.41 | 1.50 |
| | **Agroforestry system units** | **i** | Poplar+paddy-wheat | 12.27 | 6.58 | 5.69 | 20.89 |
| | | **ii** | Toona+maize-wheat | 222.58 | 8.76 | 213.77 | 784.55 |
| Sub-temperate | **Baseline** | | Soybean-wheat | 4.53 | 4.40 | 0.14 | 0.51 |
| | **Agroforestry system** | | Grewia+soybean-wheat | 19.19 | 3.96 | 15.24 | 55.92 |
| Wet-temperate | **Baseline** | | Maize-wheat | 4.17 | 4.04 | 0.13 | 0.46 |
| | **Agroforestry system** | | Quercus+ maize-wheat | 11.68 | 3.64 | 8.04 | 29.51 |
| Dry-temperate | **Baseline** | | Barley | 3.62 | 3.55 | 0.07 | 0.26 |
| | **Agroforestry system** | | Poplar+barley | 29.86 | 3.20 | 26.67 | 97.87 |

* Carbon emitted during the year of observations recorded.

** Total carbon locked in biomass of woody perennials uptill the age when observations were recorded.

**26B) Agri-horti-silviculture System**

| Climate type | Functional component | | | Total carbon sequestered (Mg/ha) | Total carbon emitted (Mg/ha) | Likely $CO_2$ mitigation | |
|---|---|---|---|---|---|---|---|
| | | | | | | Net carbon locked (Mg/ha) | Net $CO_2$ locked (Mg/ha) |
| Sub-tropical | **Baseline** | **i** | Paddy-wheat | 7.53 | 7.31 | 0.23 | 0.83 |
| | | **ii** | Maize –wheat | 10.19 | 9.78 | 0.41 | 1.50 |
| | **Agroforestry system units** | **i** | Mango+Poplar+ Paddy-wheat | 15.53 | 7.48 | 8.04 | 29.51 |
| | | **ii** | Mango+Grewia+ Paddy-wheat | 24.15 | 10.14 | 14.01 | 51.43 |
| | | **iii** | Mango+Toona+ Maize –wheat | 69.71 | 9.48 | 60.24 | 221.07 |
| Sub-temperate | **Baseline** | | Soybean -wheat | 4.53 | 4.40 | 0.14 | 0.51 |
| | **Agroforestry system units** | **i** | Plum+Morus+ Soybean -wheat | 9.92 | 6.10 | 3.82 | 14.02 |
| | | **ii** | Peach+Grewia+ Soybean -wheat | 11.06 | 7.37 | 3.69 | 13.56 |

**26C) Agri-horticulture System**

| Climate type | System component | | | Total carbon sequestered (Mg/ha) | Total carbon emitted (Mg/ha) | Likely $CO_2$ mitigation | |
|---|---|---|---|---|---|---|---|
| | | | | | | Net carbon locked (Mg/ha) | Net $CO_2$ locked (Mg/ha) |
| Sub-tropical | **Baseline** | | Paddy-wheat | 7.53 | 7.31 | 0.23 | 0.83 |
| | **Agroforestry system** | | Mango+Paddy-wheat | 19.72 | 8.26 | 11.46 | 42.06 |
| Sub-temperate | **Baseline** | **i** | Soybean -wheat | 4.53 | 4.40 | 0.14 | 0.51 |
| | | **ii** | Cabbage-frenchbean | 11.14 | 10.80 | 0.33 | 1.22 |
| | **Agroforestry system units** | **i** | Peach+Soybean - wheat | 13.09 | 6.87 | 6.23 | 22.86 |
| | | **ii** | Apple+cabbage-frenchbean | 27.18 | 13.50 | 13.68 | 50.21 |
| Wet-temperate | **Baseline** | | Potato | 1.07 | 1.07 | 0 | 0 |
| | **Agroforestry system** | | Apple+Potato | 22.13 | 13.61 | 8.52 | 31.26 |
| Dry-temperate | **Baseline** | | Pea | 1.93 | 1.81 | 0.12 | 0.43 |
| | **Agroforestry system** | | Apple+Pea | 33.52 | 14.83 | 18.68 | 68.57 |

**26D) Silvi-pastoral System**

| Climate type | System component | | | Total carbon sequestered (Mg/ha) | Total carbon emitted (Mg/ha) | Likely $CO_2$ mitigation | |
|---|---|---|---|---|---|---|---|
| | | | | | | Net carbon locked (Mg/ha) | Net $CO_2$ locked (Mg/ha) |
| Sub-tropical | **Baseline** | | Natural grass | 2.82 | 2.76 | 0.06 | 0.21 |
| | **Agroforestry system units** | **i** | *Acacia catechu*+ Natural grass | 30.92 | 2.21 | 28.71 | 105.37 |
| | | **ii** | *Grewia optiva*+ Natural grass | 24.02 | 1.04 | 22.98 | 84.34 |
| Sub-temperate | **Baseline** | | Natural grass | 2.28 | 2.19 | 0.09 | 0.33 |
| | **Agroforestry system units** | **i** | *Acacia catechu*+ Natural grass | 10.20 | 2.34 | 7.86 | 28.85 |
| | | **ii** | *Grewia optiva*+ Natural grass | 12.42 | 1.86 | 10.57 | 38.78 |
| | | **iii** | *Pinus roxburghii*+ Natural grass | 115.06 | 0.68 | 114.39 | 419.79 |
| Wet-temperate | **Baseline** | | Natural grass | 1.62 | 1.59 | 0.03 | 0.12 |
| | **Agroforestry system units** | **i** | Quercus+ Natural grass | 43.67 | 0.86 | 42.81 | 157.11 |
| | | **ii** | Robinia+ Natural grass | 3.86 | 1.53 | 2.33 | 8.54 |
| Dry-temperate | **Baseline** | | Natural grass | 1.63 | 1.60 | 0.03 | 0.12 |
| | **Agroforestry system units** | **i** | Salix+ Natural grass | 72.74 | 1.09 | 71.65 | 262.95 |
| | | **ii** | Robinia+ Natural grass | 3.24 | 1.33 | 1.91 | 7.02 |

1. **To document the current knowledge base of impact of climatic variability and climate change on soil organic carbon stocks in different agro-ecological regions.**

Documentation in the form of Status Report on *Impact, Adaptation and mitigation of climatic variability and climate change on soil organic carbon status – an Indian perspective* has been submitted.

2. **To evaluate the soil carbon stock under different agro-ecological regions of India.**

To evaluate the soil carbon stock under different agro-ecological regions soil profile samples were collected from Agro-ecological regions 12 and 18 covering coastal districts of Orissa, 15 covering the lower indo-gangetic planes of West Bengal, Agro-ecological region 10 covering the Malwa region of Madhya Pradesh and Agro-ecological region 4 (Delhi). Soil samples were collected from cultivated soils as well as from pristine soils nearer to the cultivated soils to compare the change in soil organic carbon (SOC) status due cultivation practices and over time. The sites for sampling were selected based on the variation in the land use systems. Soil samples were analyzed for total organic carbon, micro and macro aggregate distribution, aggregate linked organic carbon and texture. The soil types, cropping systems and their duration at the sampling locations were also noted. The salient finding of the study are given below:

### 2.1. Agro-ecological region 12 and 18 (Coastal Agro-ecosystem of Orissa)

Most of the soils collected from coastal Orissa were alluvial in nature as it was the dominant soil type in the regions and the dominant cropping systems were rice-based. The texture of the soil varied between loamy sand to silty clay loam with occasional occurrence of sand in the deeper layer of the profile. The bulk density ranged between 1.45 and 1.77 Mg $m^{-3}$ at different depths in the soil profile and the SOC content was low to medium. The soil organic carbon content of the pristine soils was higher than those of cultivated soils. The reduction of carbon as compared to pristine soil was due to cultivation practices. The percentage loss of carbon in cultivated soils as compared to pristine soils is given in Table 2.1.1. The loss of carbon (0-15 cm soil depth) from cultivated soils as compared to pristine soils ranged between 33 - 71 %. It was further observed that the loss of carbon from 0-5 cm soil was relatively much higher compared to that from 5-15 cm soil. Besides this, SOC in surface soil was higher than SOC in deeper soils in most of the profiles. This is because of the disturbance of soil through cultivation, which leads to the emission of carbon as carbon dioxide from soil through biogeochemical reactions (decomposition of organic matter).

Table 2.1.1. Effect of cultivation practices on loss of soil organic carbon from the *coastal alluvial soils of Orissa.*

| Depth (cm) | Decrease in soil organic carbon (%) from cultivated soils as *compared to pristine soils* | | | | |
|---|---|---|---|---|---|
| | Kalyan pur | Tangi | Kishore nagar | Vedapur | Govind ram patna |
| 0-5 | 29 | 93 | 22 | 88 | 10 |
| 5-15 | 38 | 50 | 2 | 46 | 58 |
| 15-30 | 17 | 12 | 0 | 12 | 36 |
| 30-45 | 10 | 24 | 0 | 0 | 47 |
| 45-60 | 17 | 9.2 | 0 | 0 | 34 |
| 60-75 | 0 | 5 | 0 | 0 | 0 |

The per cent macro-aggregate in pristine soils was higher than in cultivated soils. Further, the puddled soils showed higher micro-aggregates in comparison to pristine soils (Fig. 2.1.1.) because the intensive puddling operation broke the soil aggregates to smaller size fractions and increased the micro-aggregates formation. Texturally silty loam soils under puddled rice had less micro-aggregates than sandy loam soils under similar management conditions.

The data clearly indicated that in all samples irrespective of texture, cropping systems, and climate, the carbon content followed the order: Macro-aggregate-C > Micro-aggregate-C > Silt + clay-C (Fig. 2.1.2). There was a positive significant correlation between macro-aggregates and its carbon content while a significant negative correlation was found between micro-aggregate and its carbon content in coastal alluvial soils of Orissa (Fig. 2.1.3).

## 2.2. Agro-ecological regions 15 (lower Indo-gangetic plains of West Bengal)

Farmers at Agro-ecological region 15 (West Bengal) followed paddy-based cropping systems. The climate is hot sub-humid (moist) to humid and the soils are alluvium-derived. The soil organic carbon contents of pristine soils were higher than those of cultivated soils (Table 2.2.1). The loss of SOC was higher in 0-5 and 5-15 cm soil layers and averaged to about 32%. The loss of SOC from upper soil layers in comparison to deeper layers was rapid. The soils with higher clay content contained higher SOC, and the effect of cropping system on SOC was not discernible. The bulk density (BD) ranged from 1.4 to 1.65 Mg $m^{-3}$ in the soil

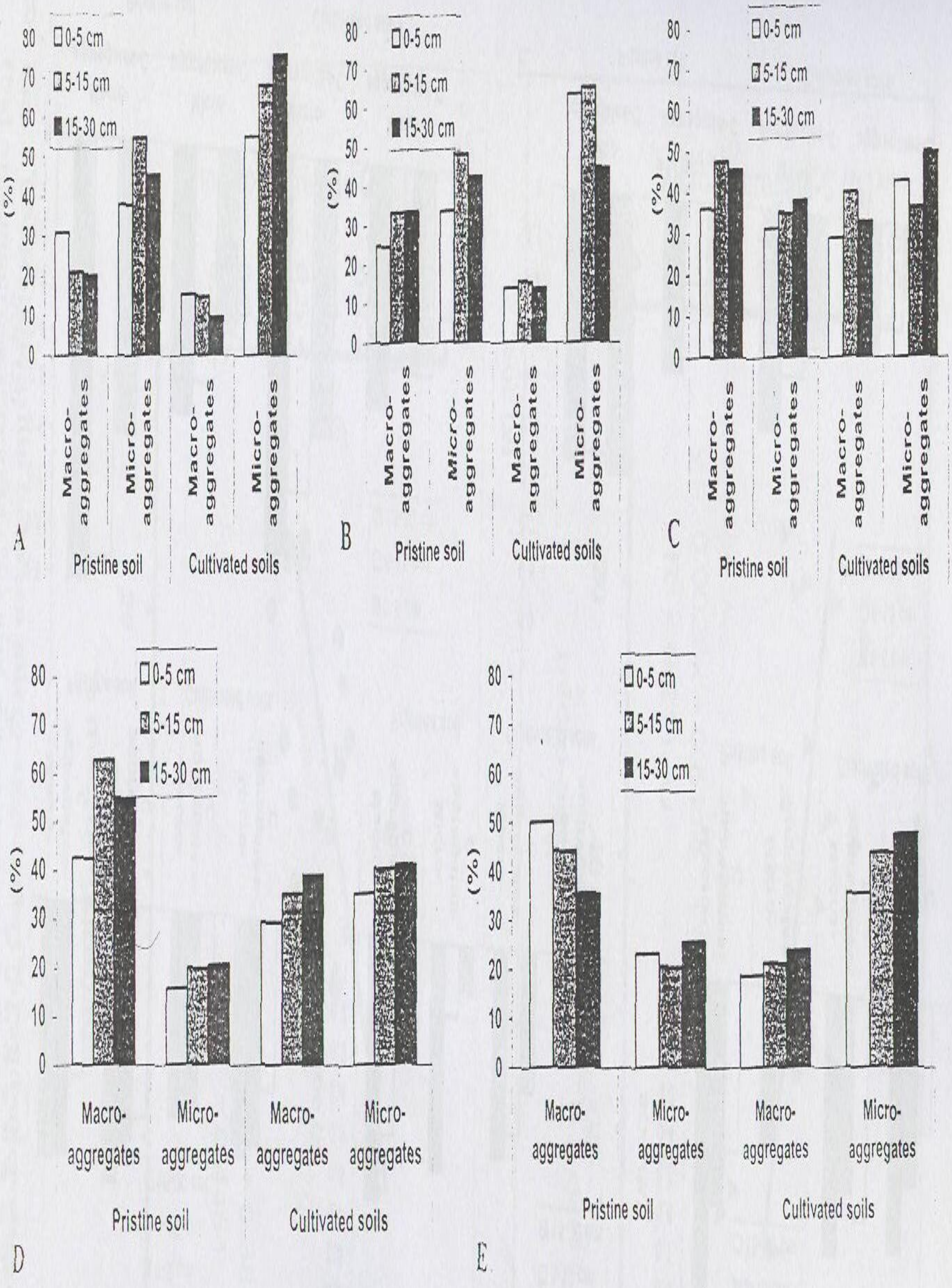



Fig. 2.1.1. Macro- and micro-aggregate distribution in different soils in coastal agro-ecosystems of Orissa (A: Kalyanpur; B: Tangi; C: Kishorenagar; D: Vedapur; E: Govindrampatna)

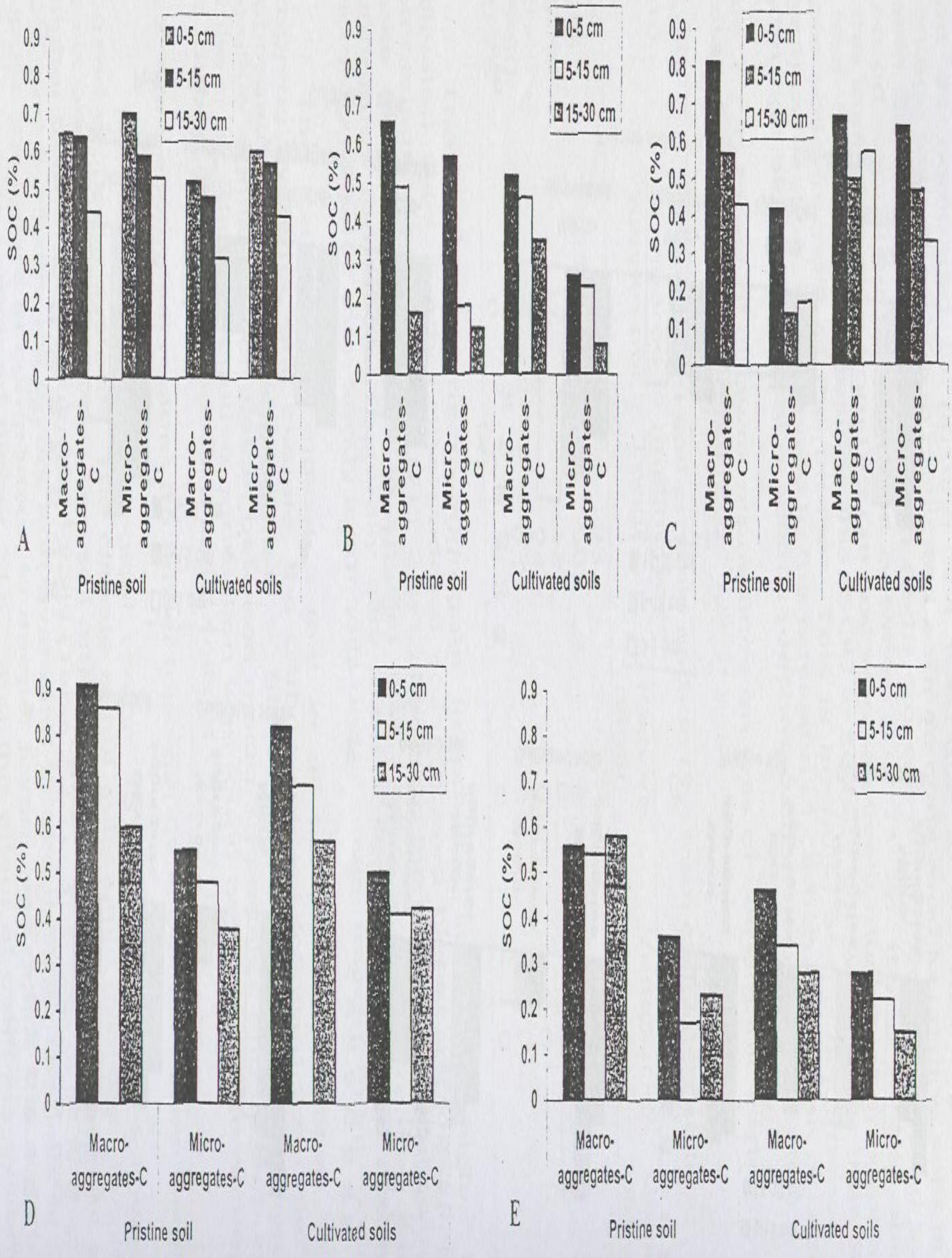
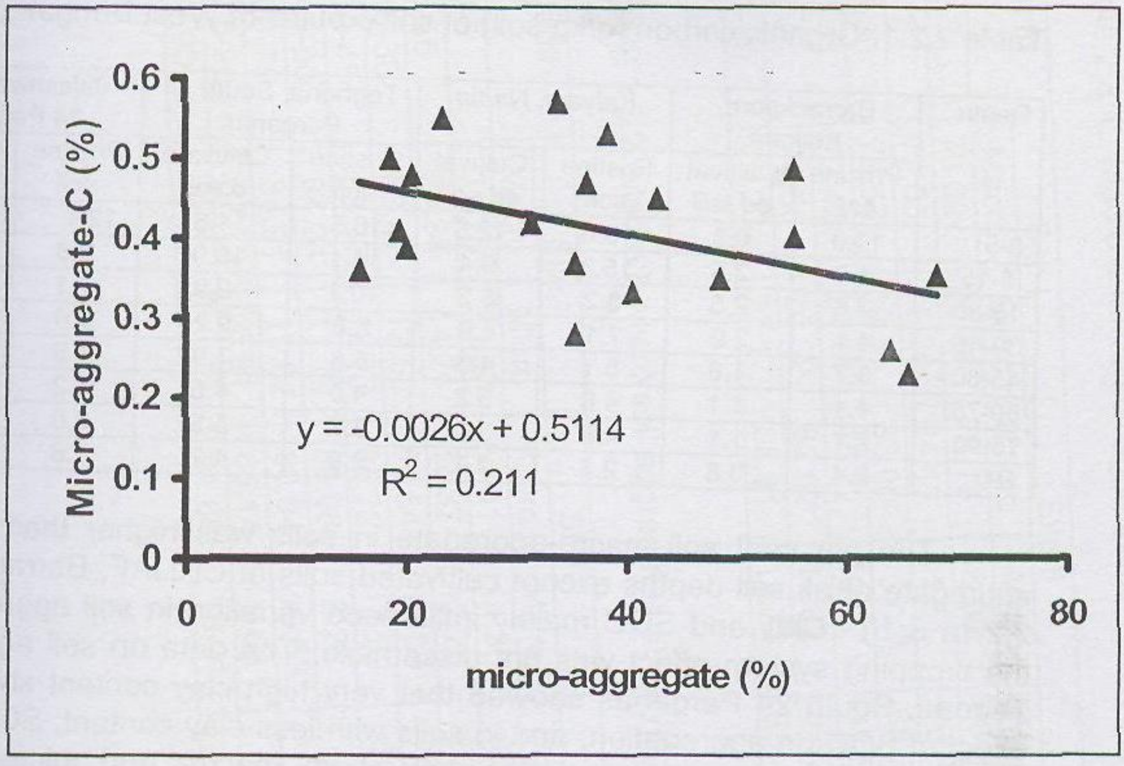



Fig. 2.1.2. Macro- and micro-aggregate-Carbon distribution in different soils in coastal agro-ecosystems of Orissa. (A: Kalyanpur; B: Tangi; C: Kishorenagar; D: Vedapur; E: Govindrampatna)



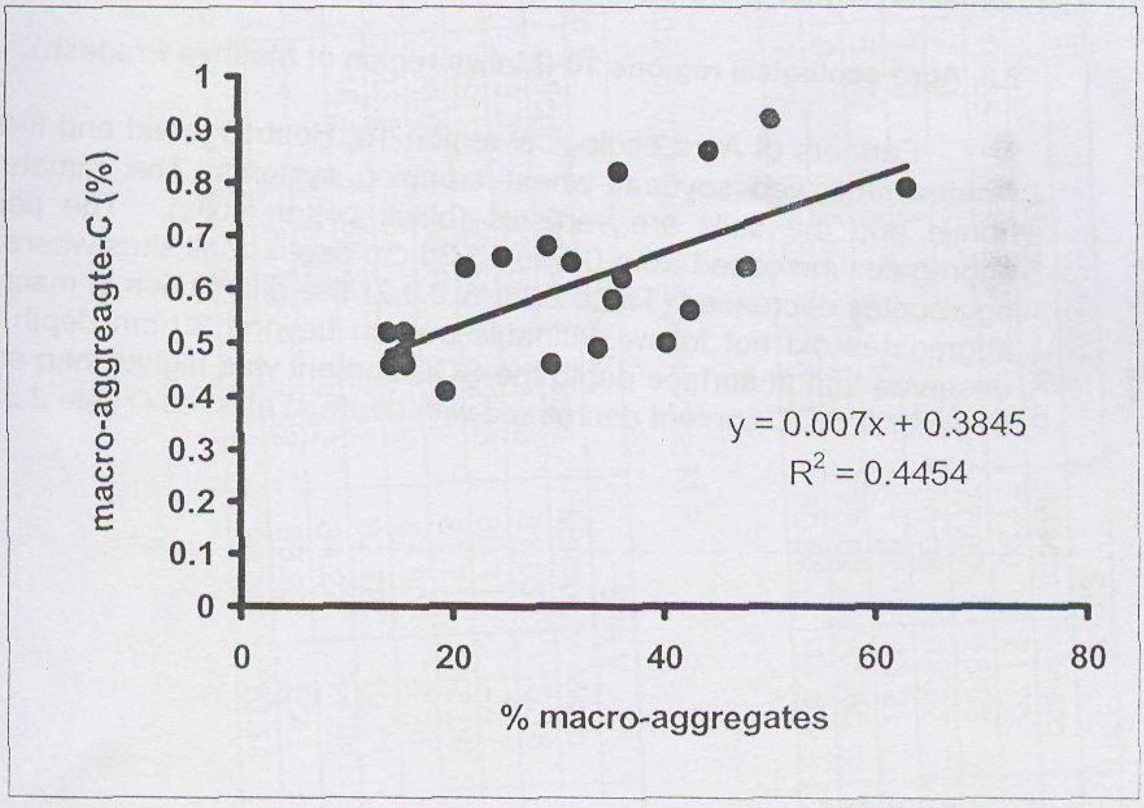




**Fig. 2.1.3. Relationship between micro-aggregate (%) and micro-aggregate-C (%) and macro-aggregate (%) and macro-aggregate-C (%) under coastal agro-ecosystems of Orissa.**

profile. The BD values at varying soil depths of undisturbed soil profiles were slightly lower than those of cultivated soil profiles.

Table 2.2.1. Organic carbon (g/kg soil) of soil profiles of West Bengal

| Depth | Barrackpore, Kolkata | | Kalyani, Nadia | | Teghoria, South 24 Parganas | | Jaleshwar, North 24 Parganas | |
|---|---|---|---|---|---|---|---|---|
| | Pristine soil | Cultivated soil | Pristine soil | Cultivated soil | Pristine soil | Cultivated soil | Pristine soil | Cultivated soil |
| 0-5 | 11.0 | 6.3 | 15.0 | 12.8 | 16.5 | 14.6 | 12.1 | 7.8 |
| 5-15 | 4.7 | 2.5 | 15.3 | 9.4 | 14.1 | 10.9 | 9.8 | 6.2 |
| 15-30 | 3.6 | 2.5 | 8.2 | 6.2 | 10.1 | 9.9 | 7.1 | 5.3 |
| 30-45 | 4.1 | 2.9 | 7.1 | 4.9 | 8.8 | 9.2 | 5.6 | 6.4 |
| 45-60 | 3.7 | 1.8 | 5.1 | 4.3 | 5.8 | 7.9 | 4.5 | 6.1 |
| 60-75 | 4.1 | 1.1 | 4.8 | 5.2 | 4.5 | 6.6 | 5.2 | 5.4 |
| 75-90 | 2.7 | 1.1 | 4.5 | 3.0 | 3.7 | 5.3 | 3.0 | 3.2 |
| >90 | 2.4 | 0.8 | 2.7 | 2.1 | 2.9 | 4.2 | 1.6 | 1.9 |

The per cent soil macro-aggregate in soils was higher than soil micro-aggregate at all soil depths except cultivated soils at CRIJAF, Barrackpore (Fig. 2.2.1a & b). Clay and SOC mainly influenced variation in soil aggregation and the cropping system effect was not discernible. The data on soil aggregates at Tegoria, South 24 Parganas showed that very high clay content shadowed the effect of SOC on aggregation, and in soils with less clay content, SOC had clear effect on aggregation. In pristine soils, both macro- and micro-aggregates contained higher OC than in cultivated soils at all depths (Fig. 2.2.2).

**2.3. Agro-ecological regions 10** (Malwa region of Madhya Pradesh)

Farmers of Agro-ecological region 10, Hoshangabad and Indore, Madhya Pradesh followed soybean-wheat cropping systems. The climate is hot sub-humid and the soils are vertisols (black cotton soils). The percent macro-aggregates increased from 0-5 to 15-30 cm depth at all sites whereas the micro-aggregates decreased (Table 2.3.1 & 2.3.2) The distribution of macro- and micro-aggregates did not follow definable pattern beyond 30 cm depth. It was also observed that at surface depth the SOC content was higher than at lower depth. In general, SOC content decreased with depth at all sites (Table 2.3.3 & 2.3.4).

Table 2.3.1. Macro & Micro soil aggregates at varying depths of different sites at Hoshangabad, M.P.

| Depth | Site I | | Site II | | Site III | | Site IV | | Site V | | Site VI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Macro | Micro | Macro | Micro | Macro | Micro | Macro | Micro | Macro | Micro | Macro | Micro |
| 0-5 | 70.02 | 25.91 | 79.17 | 16.98 | 86.31 | 10.35 | 74.13 | 21.44 | 71.60 | 21.70 | 53.42 | 39.62 |
| 5-15 | 77.06 | 18.06 | 84.19 | 11.51 | 88.89 | 7.54 | 80.81 | 12.70 | 77.89 | 15.63 | 66.26 | 30.05 |
| 15-30 | 75.57 | 19.31 | 83.90 | 13.08 | 88.53 | 7.09 | 83.24 | 12.84 | 80.08 | 14.07 | 62.41 | 13.26 |
| 30-45 | 72.42 | 24.14 | 85.72 | 10.27 | 89.52 | 8.01 | 84.57 | 11.53 | 81.57 | 13.21 | 58.41 | 39.82 |
| 45-60 | 74.58 | 20.52 | 82.52 | 14.82 | 87.23 | 9.52 | 84.89 | 11.12 | 78.02 | 15.95 | 63.19 | 28.92 |
| 60-90 | 75.20 | 22.17 | 83.81 | 13.73 | 88.45 | 7.12 | 85.25 | 1053 | 80.52 | 14.81 | 67.09 | 29.49 |

Table 2.3.2. Macro & Micro soil aggregates at varying depths of different sites at Indore, M.P.

| Depth | Site I | | Site II | | Site III | | Site IV | | Site V | | Site VI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Macro | Micro | Macro | Micro | Macro | Micro | Macro | Micro | Macro | Micro | Macro | Micro |
| 0-5 | 71.73 | 23.57 | 81.41 | 14.38 | 66.74 | 25.85 | 83.46 | 11.63 | 81.03 | 15.18 | 75.86 | 18.21 |
| 5-15 | 79.34 | 14.71 | 82.37 | 12.78 | 63.84 | 29.11 | 80.51 | 12.88 | 80.11 | 12.37 | 80.09 | 16.41 |
| 15-30 | 83.47 | 12.53 | 84.54 | 13.09 | 71.41 | 20.82 | 88.14 | 9.79 | 81.71 | 10.09 | 83.91 | 12.95 |
| 30-45 | 83.37 | 12.73 | 85.72 | 11.59 | 69.21 | 23.56 | 84.11 | 13.90 | 83.80 | 8.74 | 83.67 | 12.23 |
| 45-60 | 84.04 | 11.79 | 88.96 | 8.26 | 77.06 | 18.47 | 85.82 | 7.91 | 82.78 | 10.71 | 90.45 | 8.70 |
| 60-75 | 84.91 | 10.82 | 80.64 | 10.83 | | | 85.38 | 9.82 | 84.27 | 11.68 | 91.08 | 7.75 |
| 75-90 | 87.73 | 8.91 | 86.14 | 6.63 | | | 89.69 | 7.52 | 83.99 | 8.41 | | |
| > 90 | | | 81.68 | 10.31 | | | 88.50 | 9.18 | 84.65 | 10.11 | | |

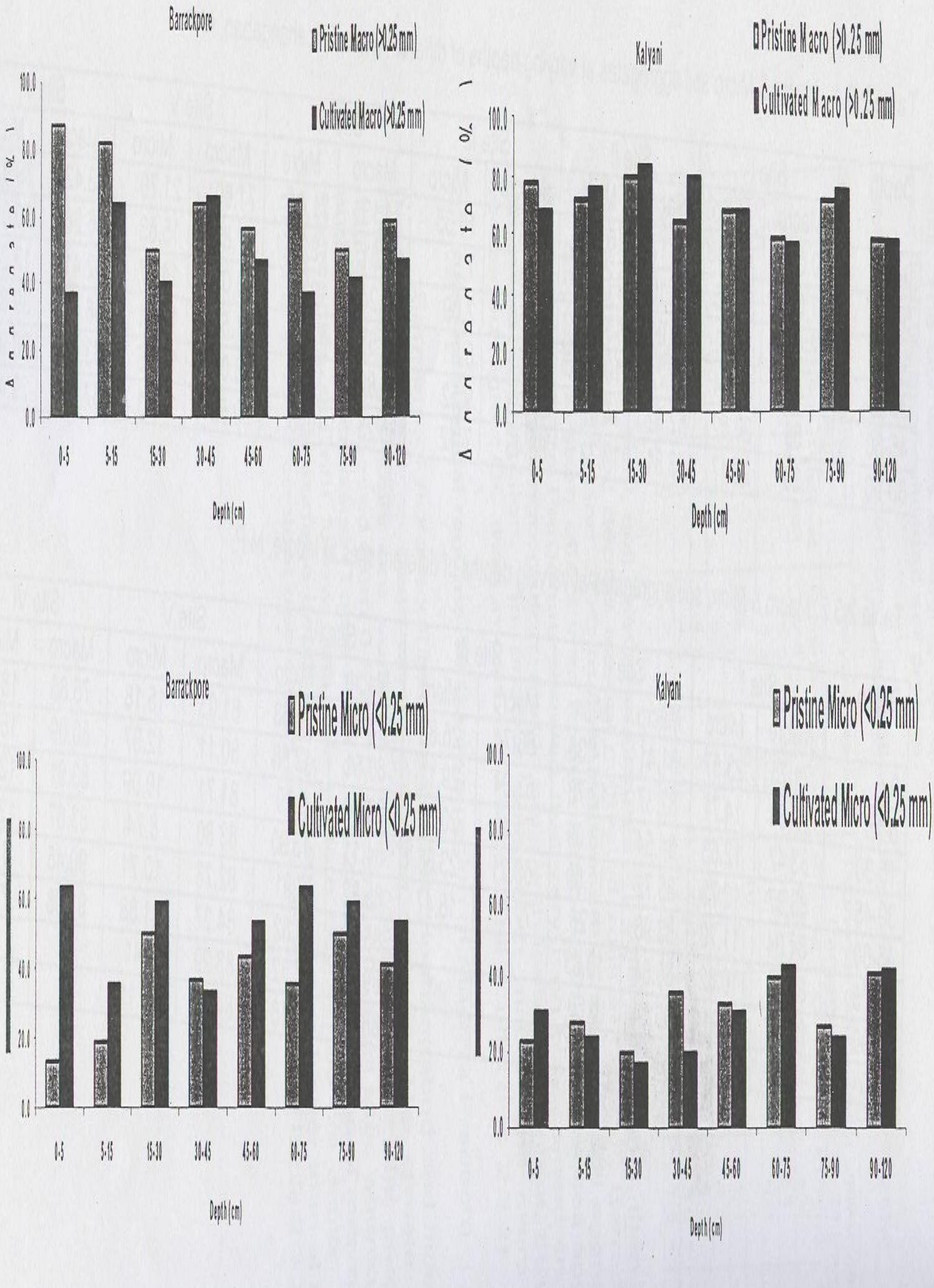



Fig. 2.2.1a. Distribution of soil macro- and micro-aggregation at Barrackpore and Kalyani of the Indo-Gangetic plains of West Bengal

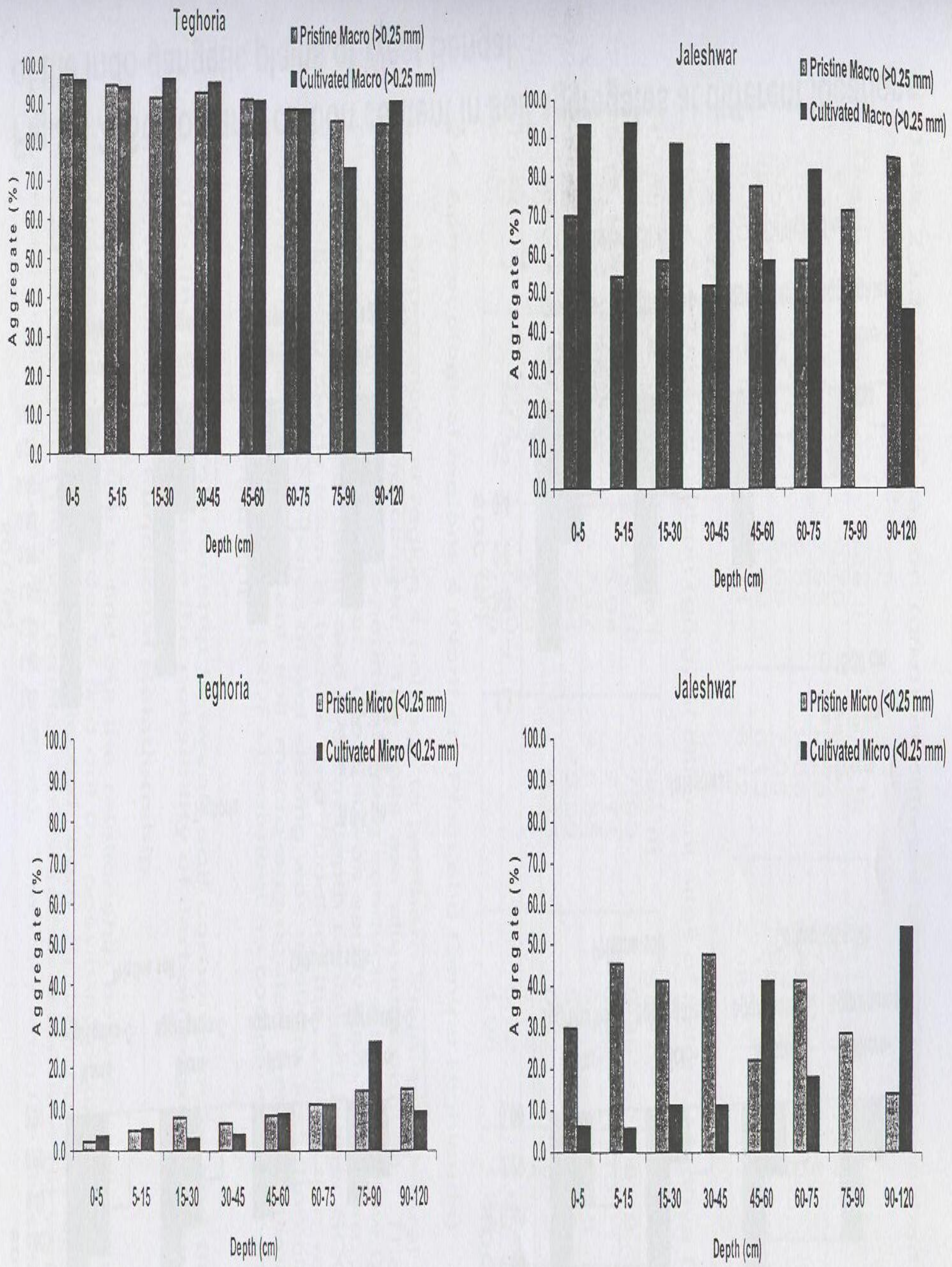



Fig. 2.2.1b. Distribution of soil macro- and micro-aggregation at Teghoria and Jaleshwar of the Indo-Gangetic plains of West Bengal

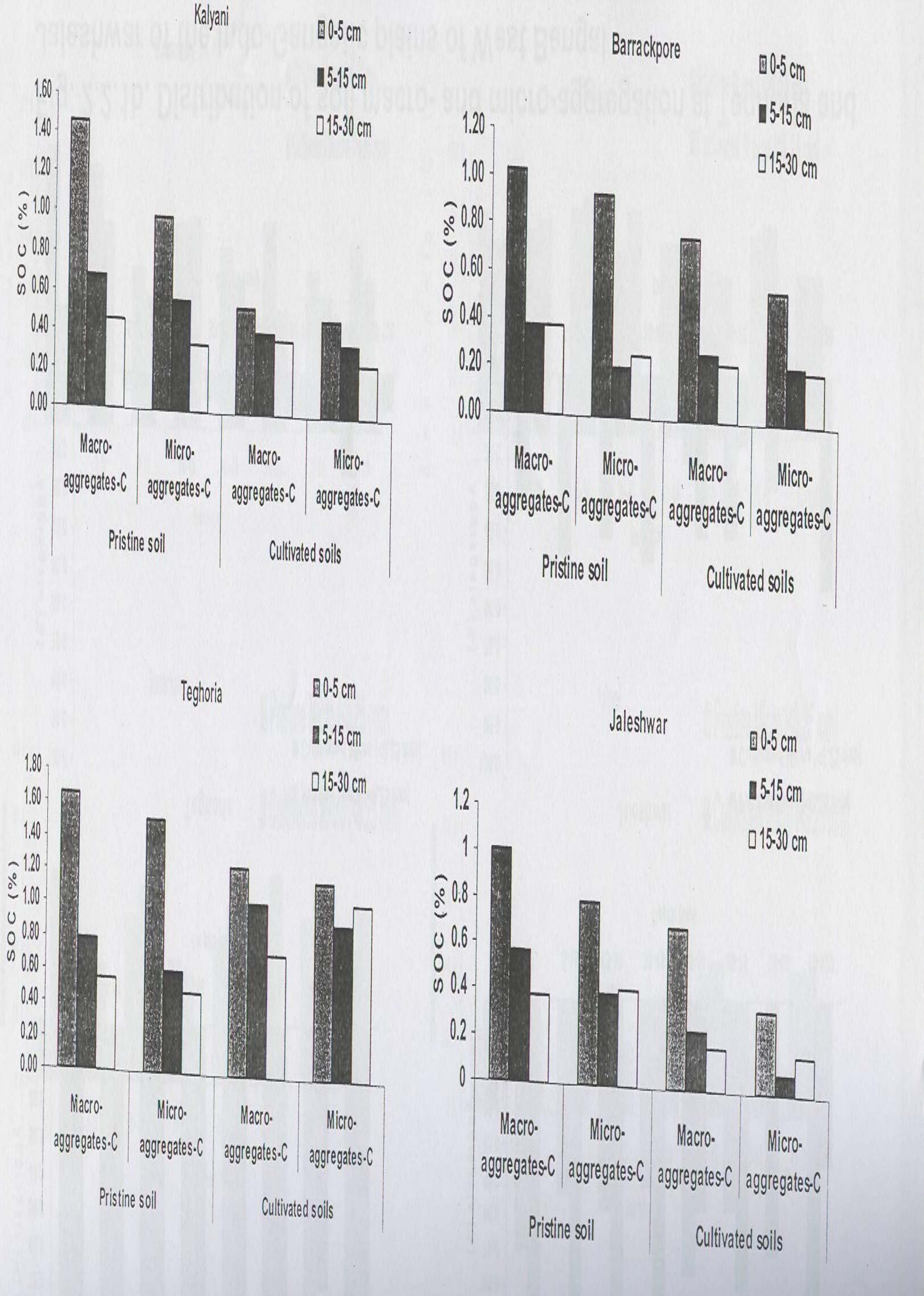



**Fig.2.2.2. Soil organic carbon content in soil aggregates at different locations of the Indo-gangetic plains of West Bengal**

Table 2.3.3. Organic carbon (g/kg) at different sites of Hoshangabad, Madhya Pradesh

| Depth | Site I | Site II | Site III | Site IV | Site V | Site VI |
|---|---|---|---|---|---|---|
| 0-5 | 5.25 | 9.70 | 9.77 | 7.64 | 7.64 | 8.90 |
| 5-15 | 4.96 | 7.53 | 9.29 | 6.73 | 6.98 | 6.41 |
| 15-30 | 4.35 | 6.37 | 9.05 | 6.69 | 6.22 | 6.18 |
| 30-45 | 3.12 | 5.09 | 7.08 | 4.92 | 5.10 | 4.87 |
| 45-60 | 2.75 | 4.69 | 6.13 | 5.17 | 4.76 | 5.08 |
| 60-90 | 2.95 | 2.71 | 6.12 | 4.98 | 3.51 | 5.24 |

Table 2.3.4. Organic carbon (g/kg) at different sites of Indore, Madhya Pradesh

| Depth | Site I | Site II | Site III | Site IV | Site V | Site VI |
|---|---|---|---|---|---|---|
| 0-5 | 12.20 | 10.18 | 7.93 | 8.35 | 8.19 | 9.22 |
| 5-15 | 11.46 | 8.04 | 7.71 | 8.48 | 10.21 | 9.49 |
| 15-30 | 10.08 | 7.17 | 6.35 | 6.25 | 6.78 | 8.69 |
| 30-45 | 8.33 | 7.61 | 5.30 | 5.21 | 5.40 | 6.80 |
| 45-60 | 7.13 | 7.92 | 4.13 | 5.42 | 6.75 | 7.37 |
| 60-75 | 7.53 | 4.56 | | 5.02 | 5.57 | 5.17 |
| 75-90 | 9.74 | 7.40 | | 5.72 | 4.65 | |
| > 90 | | 7.09 | | 4.98 | 4.23 | |

**2.4. Agro-ecological regions 4** (Northern Plain and Central Highlands)

Agro-ecological region 4 belongs to Northern Plain and Central Highlands and has hot semi-arid climate. The soils are alluvium derived. The soil was collected from a long term experiment being conducted at IARI, New Delhi. The cropping system was rice-wheat. The soil was sandy loam in texture. The SOC content decreased with depth and 0-5 cm depth contained higher SOC content. The soil being sandy loam in texture and puddled, the soil fraction retained on 0.25 mm sieve after 2 minutes of wet sieving was relatively less than clay soils of Madhya Pradesh. The percent soil macro-aggregates were relatively high in recommended dose of fertilizer (RDF) treatment as compared with control which contained less SOC than RDF.

## 3. To find out the relationship between soil carbon stocks and the factors affecting it to determine the possibility of carbon sequestration in soil.

### 3.1 Development of Functional Relationship

With the objective to find out the relationship between soil carbon stocks and factors affecting it in order to find out the possibility of carbon sequestration in soil, secondary data were collected from (i) benchmark soil of India, NBSS&LUP, Nagpur (180 soil profiles and weather data) and (ii) various other published Indian literature (72 soil profiles). The data from the sites having clay content, value of latitude and longitude of the site, bulk density, soil depth, rainfall, temperature (maximum and minimum) and soil carbon content were included as a data set for analysis. The total number of profiles was 252. For the sake of simplicity and as a first approximation, this data set was assumed to represent the SOC content for the base year 1980 as the data were collected around this year. The range of parameters in the data set is quite adequate for developing functional relationships to estimate SOC stock from the independent variables, namely, clay content, rainfall, and temperature (maximum and minimum). Studies indicated that SOC content declined when the soil was cultivated. The soil organic carbon (SOC) stock (Mg/ha) was calculated by multiplying soil organic carbon content, depth of soil and bulk density (BD) of soil of plough layer. Pedo-transfer function (Tomasella and Hondnet, 1998) was used to estimate BD where this data was missing.

A functional linear relationship between SOC stock (dependent variable) and soil clay content, rainfall, maximum temperature, minimum temperature (independent variables) was developed using multiple linear regression analysis. The following equation was developed:

$$OC = 6.364 + 0.06451\ Clay + 0.0041\ Rainfall - 0.116\ Tmax + 0.05896\ Tmin$$

$(R = 0.45^{**},\ N = 252)$ ------------- **equation 1**

Where, OC in Mg $ha^{-1}$ up to 15 cm soil depth, Clay in %, Rainfall in mm and Tmax and Tmin in $^{o}C$

In order to improve the co-efficient of determination of the relationship, a functional non-linear relationship was also developed. The developed equation is given below:

$$OC = -4.181 + 0.483\ Clay^* + 0.746\ Rainfall^* + 0.462\ T^*max - 0.211T^*min$$

$R = 0.50^{**},\ N = 252)$ ------------- **equation 2**

Where, $clay^* = 2.0321(clay)^{0.4267}$

$rain^* = 0.5908 + 0.0162(rain) - 8x10^{-6}(rain)^2 + 1.6x10^{-9}(rain)^3$

$T^*max = -10.344+1.5262(Tmax) - 0.0272(Tmax)^2$

$T^*min = 2.1628 + 1.3694\ (Tmin) - 0.0744(Tmin)^2 + 0.0012\ (Tmin)^3$

It was observed that the correlation coefficients of non-linear functional relations did not show much improvement. The data set was then rearranged according to soil orders in order to improve the coefficient of determination values of the functional relationship. The regression coefficients, constants, and $R^2$ values of the relationships of different soil orders are given in Table 3.1.1. This data also indicated that $R^2$ values did not show much improvement. Therefore, the functional linear relationship (equation 1) encompassing all the soil types was utilized to estimate the soil SOC stocks in 2020, 2050 and 2080. The scatter diagram of observed SOC and predicted SOC by equation 1 is given in Figure 3.1.1. The Figure 3.1.1 also indicated that the scatter of data around 1:1 line was widespread. The $R^2$ value of equation 1 is quite low and consequently *high uncertainty was attached with the equation in predicting SOC change with* change in climate parameters and soil clay. However, the equation can still be useful in the available models for Indian soils where SOC contents are already reduced to a low quasi equilibrium value of SOC because of intensive cultivation or cultivation with inadequate inputs. Most of the data are in the range of 2.5 to 15 Mg $ha^{-1}$ SOC while the SOC of the data set ranged from 0.23 to 33.15 Mg $ha^{-1}$.

**Table 3.1.1. Functional relationships for different soil orders**

| Organic carbon (Mg $ha^{-1}$ up to 15 cm) | | | | | | |
|---|---|---|---|---|---|---|
| Soil Orders | Regression coefficients | | | | | $R^2$ |
| | Constant | Clay (%) | Rain (mm) | Max T (°C) | Min T (°C) | |
| Vertisols | 5.372 | 2.26E-02 | 1.62E-03 | -0.124 | 0.254 | 0.097 |
| Inceptisols | 3.029 | 0.158 | 4.82E-03 | -0.11 | 4.23E-03 | 0.430 |
| Entisols | -1.812 | 7.03E-02 | 7.03E-02 | 4.42E-02 | 9.99E-02 | 0.259 |
| Aridisols | 7.034 | 1.49E-01 | 1.49E-01 | -0.175 | 0.229 | 0.252 |

*Pedo-transfer function was used to estimate BD (Tomasella and Hodnet, 1998), where BD data was missing for calculating soil organic carbon stocks*

### 3.2 Climate Change

IPCC HadCM3 model has divided India into different Grid Locations as shown in Figure 3.2.1. The data set of different sites containing clay, rainfall, SOC and minimum and maximum temperatures were averaged corresponding to these India grid locations. These average values were considered base values of 1980 for different India Grid Locations. The values of minimum temperature, maximum temperature and rainfall for the 2020, 2050 and 2080 has been estimated by using the changes in these values as predicted by IPCC HadCM3 Model for India Grid Locations. The base value of the year 1980 and predicted changed values of minimum and maximum temperatures and rainfall for the year 2020, 2050 and 2080 under A2b scenario for different grid locations are given in Fig. 3.2.2 for maximum temperature, Fig. 3.2.3 for minimum temperature and Fig. 3.2.4 for rainfall. The prediction indicated that the minimum and maximum temperatures are rising at all grid locations and the degree of rise is increasing from 2020 through 2080. The rainfall (Fig. 3.2.4) in general has also shown rising trend at all grid locations except 135, 134 and 121 where the rainfall is predicted to rise in 2020 beyond which it is expected to decrease in 2050 and 2080.

### 3.3. Soil Organic Carbon Change

Using the predicted values of rainfall, the minimum and maximum temperatures for year 2020, 2050 and 2080, the SOC stocks were predicted for these years for IPCC HadCM3 India Grid Locations using equation 1. The States and corresponding agro-ecological regions for different IPCC HadCM3 India Grid Locations are given in Table 3.3.1. The data on SOC stock (Mg $ha^{-1}$) of 1980 considered as the base year (Fig 3.3 1) and changes over it during 2020, 2050 and 2080 are given in Fig 3.3 2, Fig 3.3 3 and Fig 3.3 4, respectively. These data are arranged in two groups. The first group (values in green color) contains locations where SOC is expected to increase and second group (values in red color) belongs to locations where SOC is expected to decrease. The data indicated that maximum increase in organic stock is predicted to be in IPCC HadCM3 India Grid Location No.83. This grid corresponds to Eastern Maharashtra and parts of Chhattisgarh containing Agro-ecological Region Nos.10, 11 and 12. The increase in SOC stock was due to increase in predicted rainfall. Generally the maximum and minimum temperatures of the India grid locations are predicted to increase in 2020, 2050 and 2080. Similarly the minimum increase in SOC is predicted to be 0.09, 0.29 and 0.65 Mg $ha^{-1}$ respectively in 2020, 2050 and 2080 in IPCC HadCM3 India Grid Location No.70 covering Eastern Madhya Pradesh and parts of Chhattisgarh corresponding to agro-ecological region No.10 and 11. Though the maximum and minimum temperatures of these India Grid Locations are expected to rise, the SOC increase was attributed to predicted increase in rainfall in these regions.

The maximum decrease in SOC stock is predicted for the India Grid Location No.147 covering Southern Kerala and Southern Tamil Nadu containing agro-ecological region No. 8, 18 and 19. In these regions the rainfall and minimum and maximum temperatures are expected to rise, however, the organic carbon content is expected to decrease. The soils of these regions have comparatively high SOC stock and the decrease in SOC can perhaps be because of rise in temperature. The minimum decrease predicted at India Grid Location No.134 covering Northern Kerala and Tamil Nadu containing agro-ecological region No.8 and 19 may possibly be because of rise in predicted temperature and decrease in predicted rainfall.

**Table 3.3.1. The states of India and agro-ecological regions corresponding to IPCC HadCM3 India Grid Location**

| Sl No. | Grid No. | States | Agro-Ecological Regions |
|---|---|---|---|
| 1. | 3 | North-western parts of J&K | 1 |
| 2. | 4 | Northern parts of J&K | 1 |
| 3. | 5 | North-eastern parts of J&K | 1 |
| 4. | 16 | Western parts of J&K | 14 |
| 5. | 17 | Central parts of J&K and Northern HP | 14 |
| 6. | 29 | Western part of Punjab | 2, 4, 9 |
| 7. | 30 | Eastern part of Punjab, South HP, parts of Haryana and western part of Uttaranchal | 14, 9, 4 |
| 8. | 31 | Parts of Uttaranchal | 14 |
| 9. | 41 | Parts of Rajasthan | 2 |

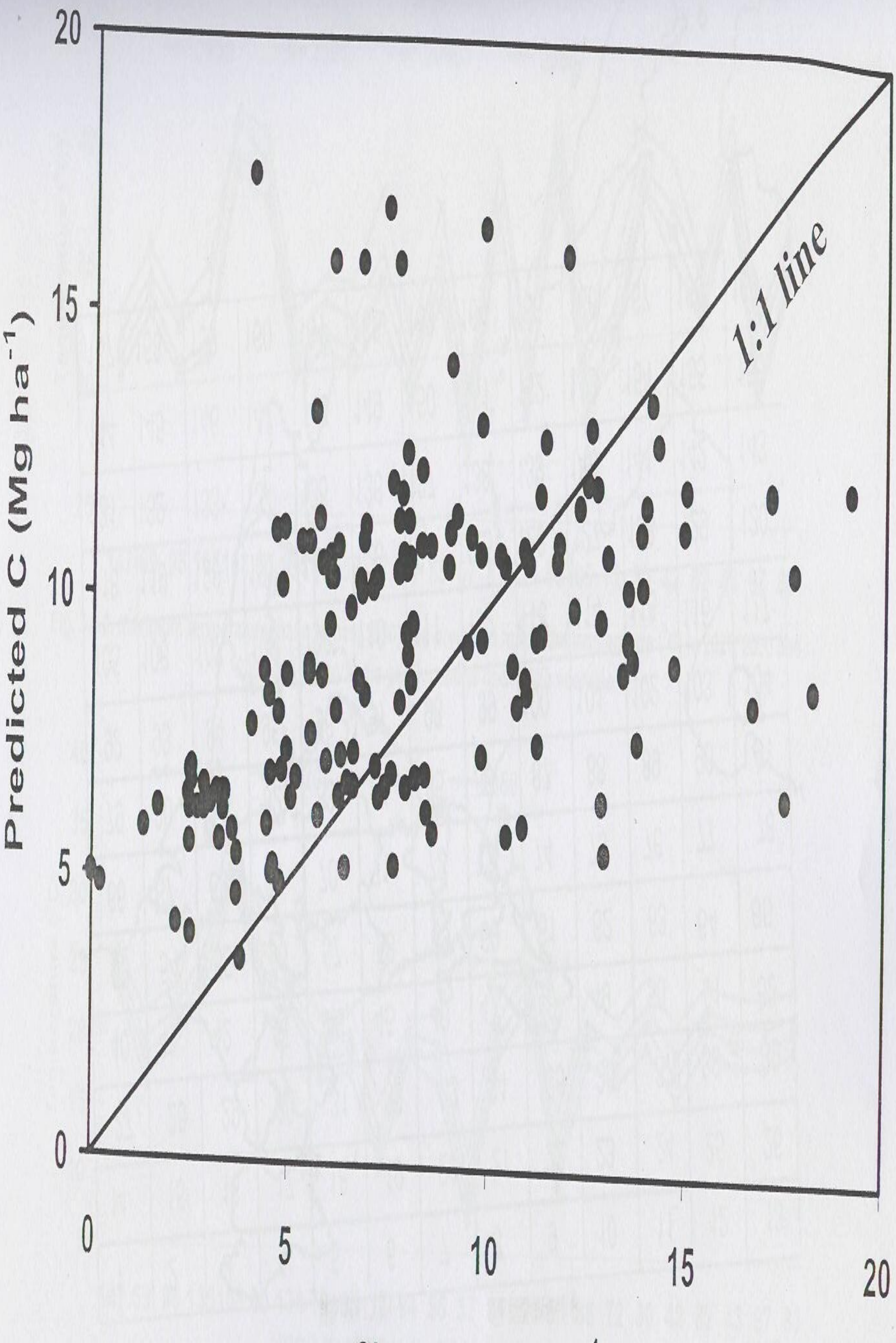
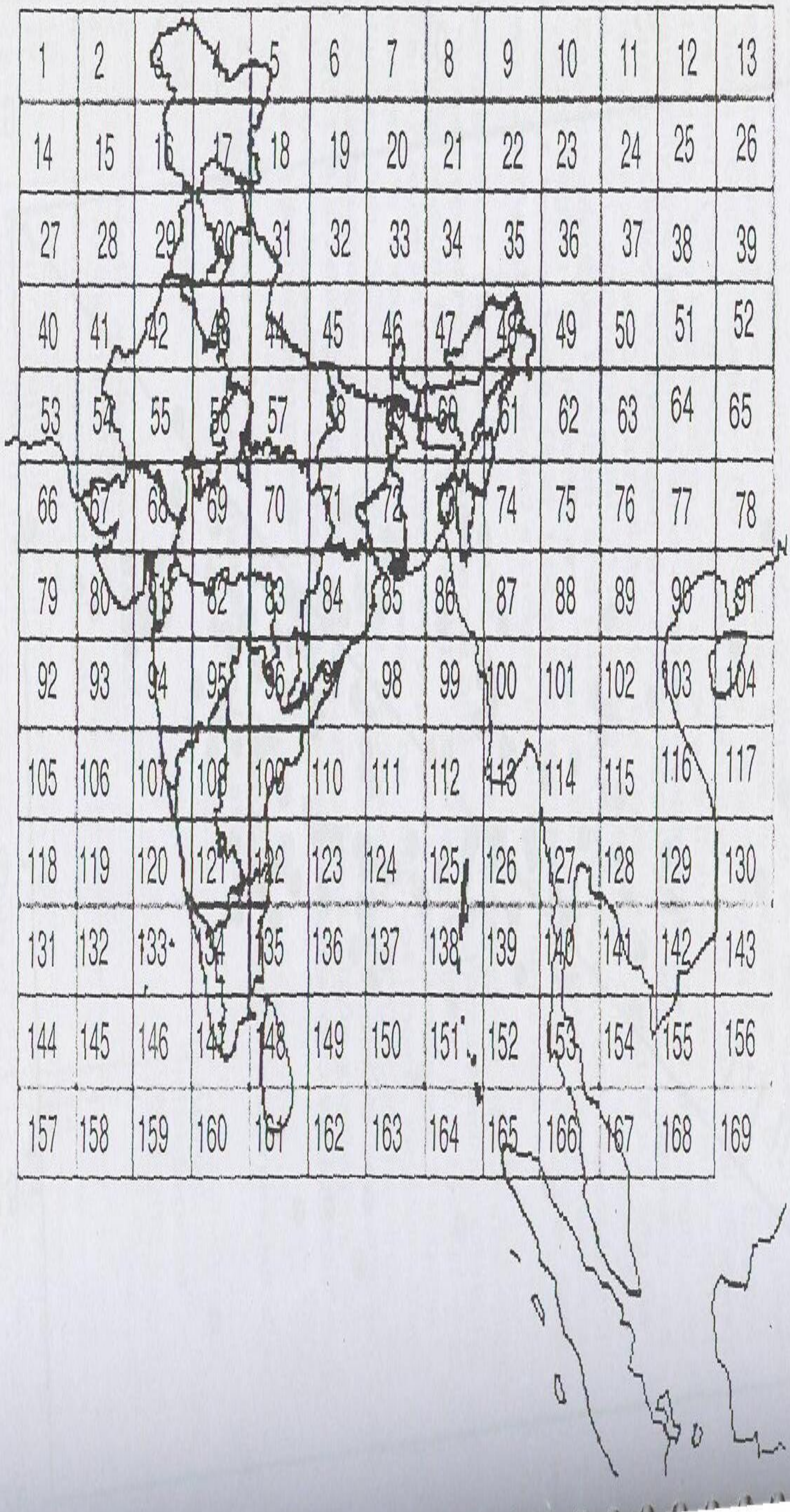



Fig. 3.1.1 Scatter diagram of soil organic carbon stock (0-15 cm)

# Fig. 3.2.1. IPCC HadCM3 India Grid Locations



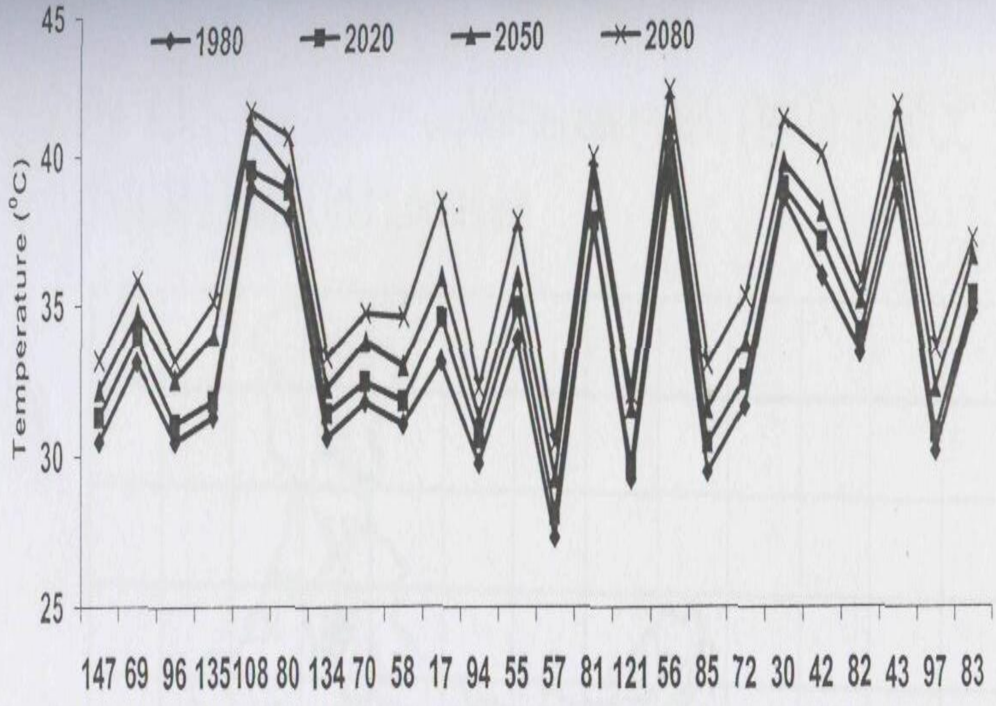



Fig. 3.2.2. Maximum temperature (base values, 1980) and predicted maximum temperature (°C) in 2020, 2050 and 2080 in different India grid locations under A2b scenario

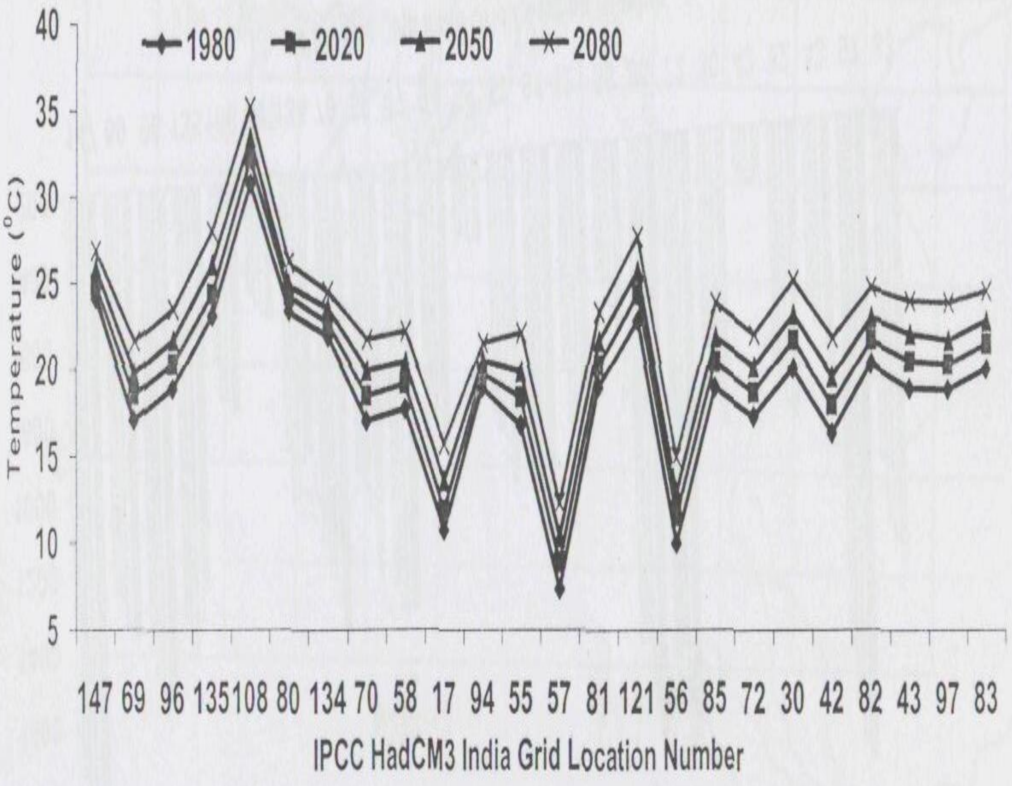



Fig. 3.2.3. Minimum temperature (base values, 1980) and predicted minimum temperature (°C) in 2020, 2050 and 2050 in different India grid locations under A2b scenario

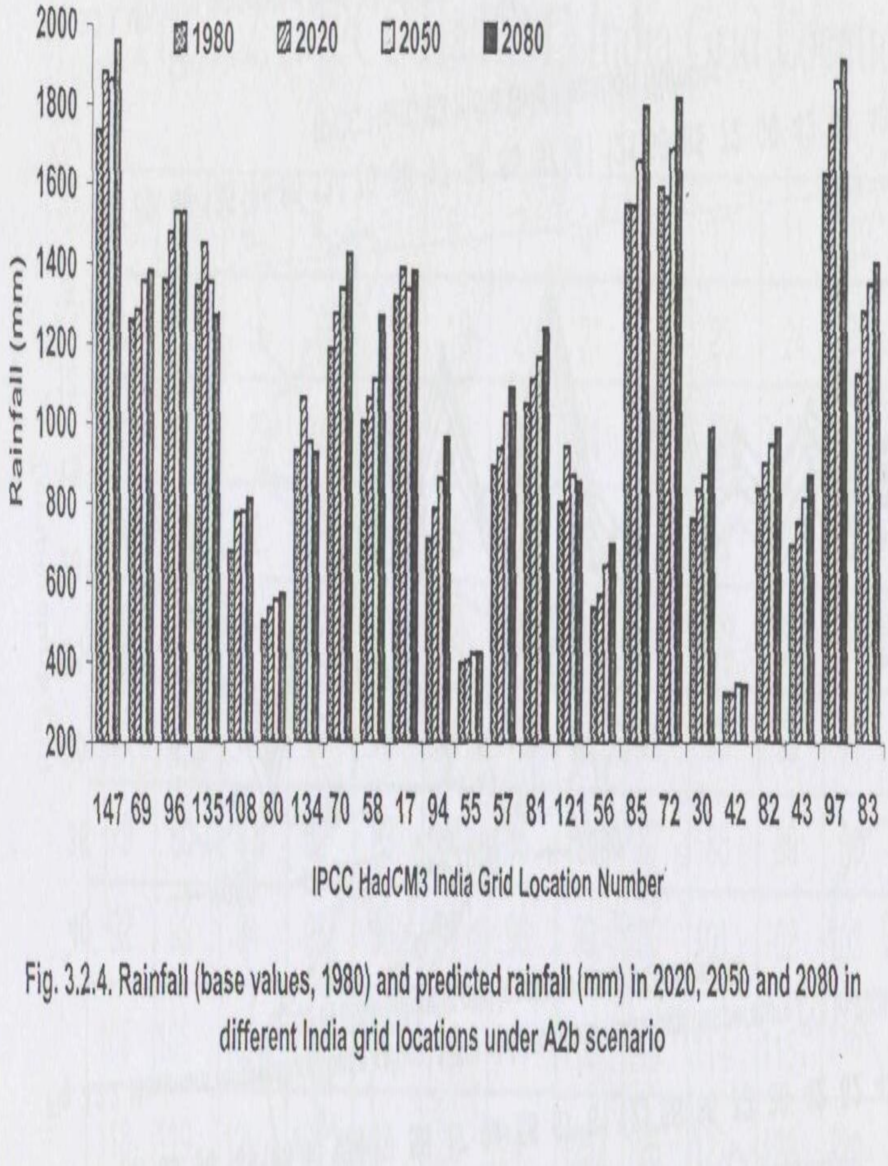



Fig. 3.2.4. Rainfall (base values, 1980) and predicted rainfall (mm) in 2020, 2050 and 2080 in different India grid locations under A2b scenario

Fig. 3.3.1. Soil organic carbon as base value (1980) at IPCC HadCM3 India Grid Locations

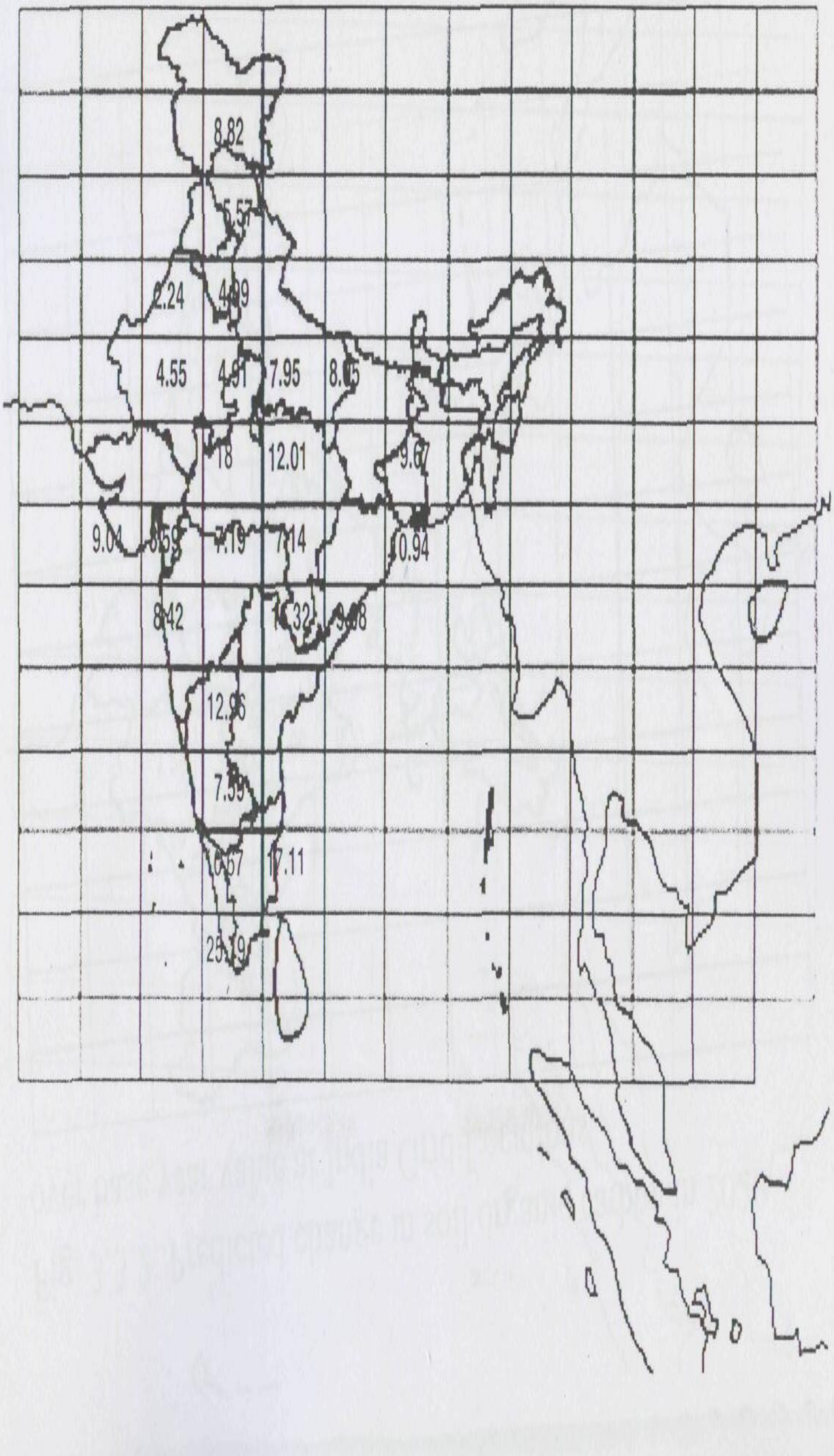


Fig. 3.3.2. Predicted change in soil organic carbon in 2020 over base year value at India Grid Locations

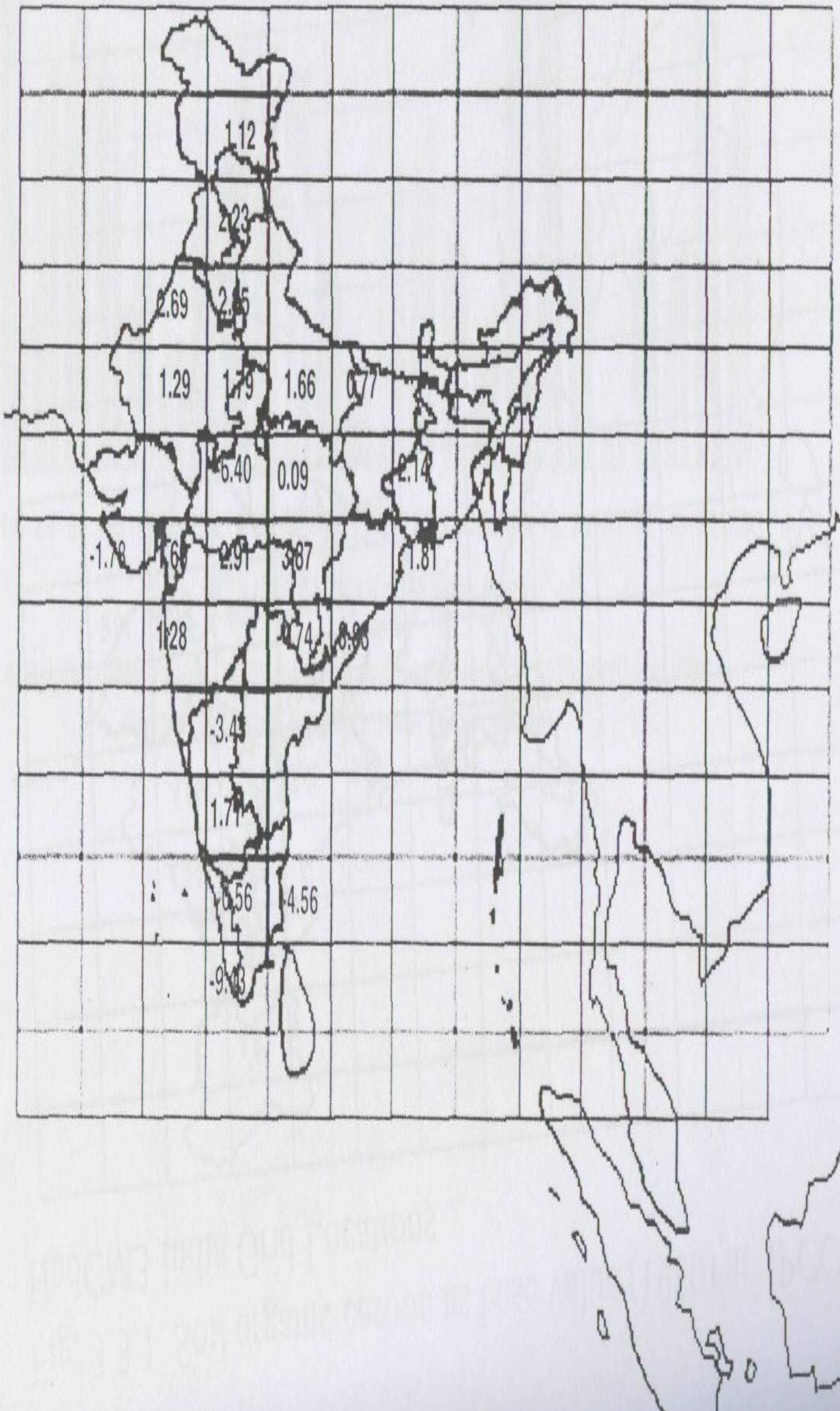


Fig. 3.3.3. Predicted change in soil organic carbon in 2050 over base year value at India Grid Locations

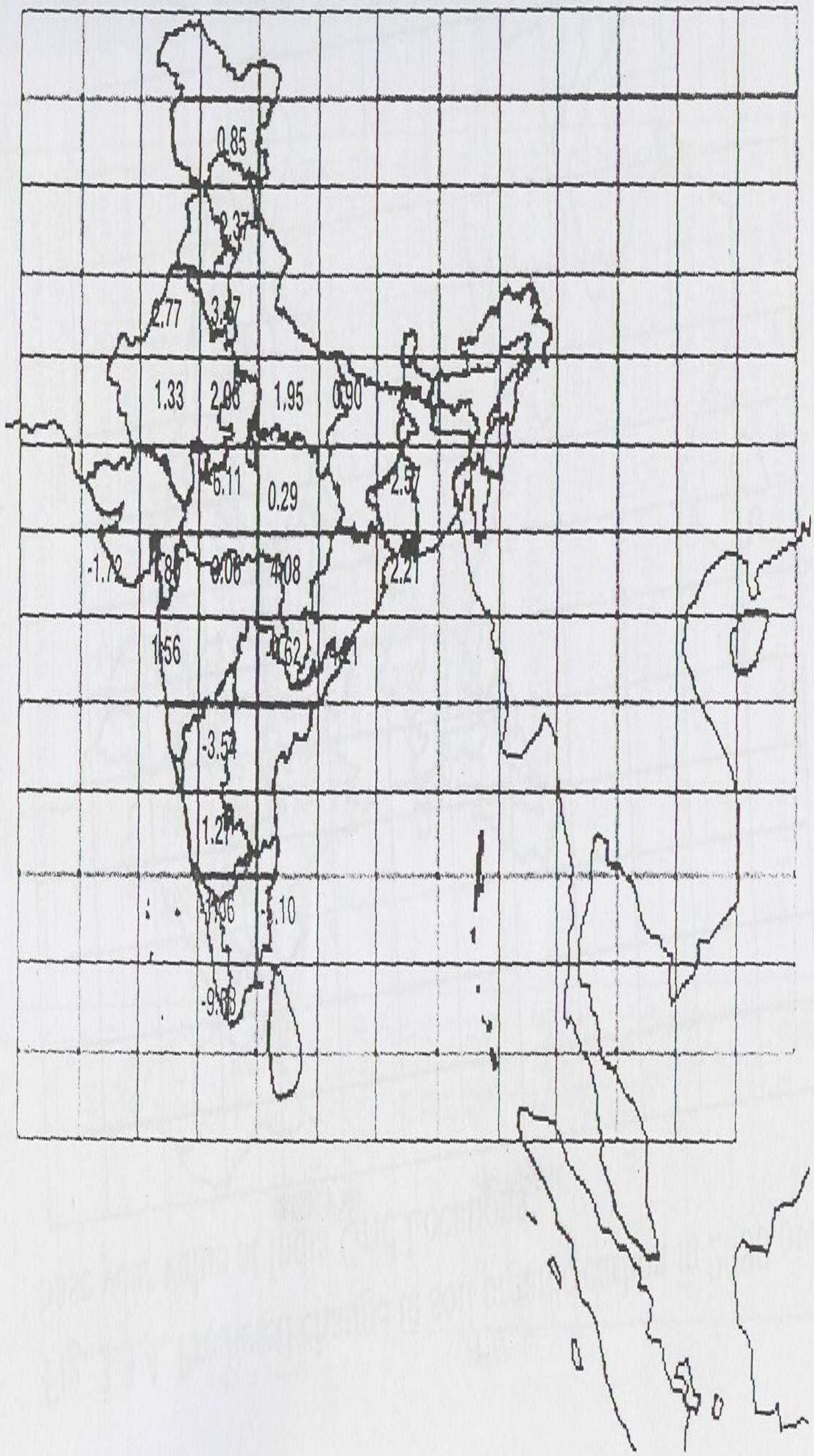
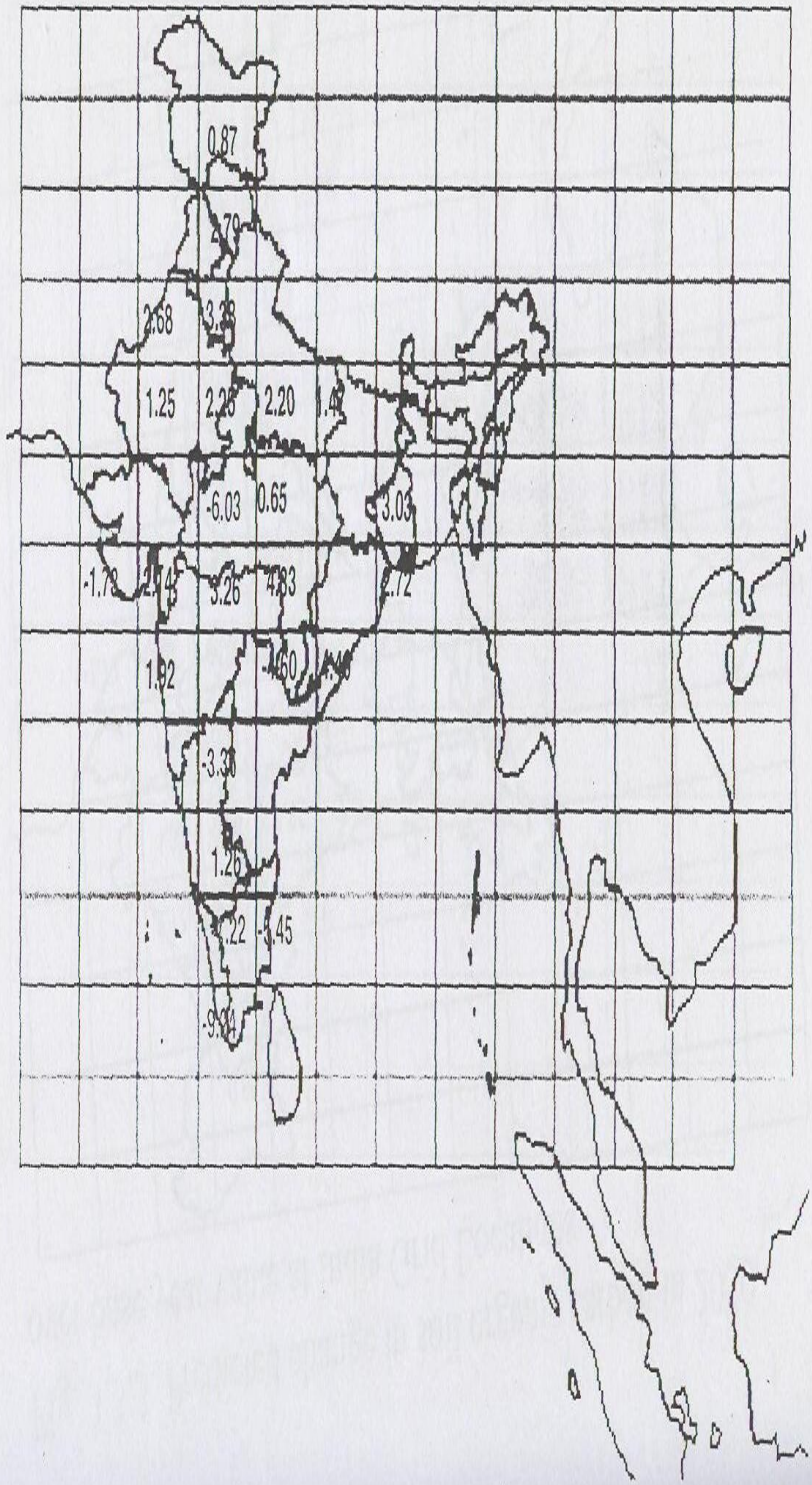


Fig. 3.3.4. Predicted change in soil organic carbon in 2080 over base year value at India Grid Locations



| | | | |
|---|---|---|---|
| 10. | 42 | Northern Rajasthan | 2 |
| 11. | 43 | Haryana, Western UP and North eastern Rajasthan | 4, 2, 9 |
| 12. | 44 | Uttaranchal and Northern part of UP | 13, 9, 14, 4 |
| 13. | 46 | Sikkim | 16 |
| 14. | 47 | Western part of Arunachal Pradesh | 16 |
| 15. | 48 | Eastern part of Arunachal Pradesh and Part of Eastern Assam | 16, 15 |
| 16. | 54 | Parts of Western Rajasthan | 2 |
| 17. | 55 | Central Rajasthan | 2, 4 |
| 18. | 56 | Eastern Rajasthan, Northern MP | 4, 5 |
| 19. | 57 | UP | 4, 9, 13 |
| 20. | 58 | Eastern Up and Western Bihar | 13, 9 |
| 21. | 59 | Eastern Bihar, Northern Bengal | 13, 15, 16 |
| 22. | 60 | Assam, Meghalaya | 15, 17 |
| 23. | 61 | Eastern Assam, Nagaland | 15, 17 |
| 24. | 67 | Kuch region of Gujarat | 2, 5 |
| 25. | 68 | Parts of Northern Gujarat, Southern Rajasthan, western MP | 2, 4, 5 |
| 26. | 69 | Western MP | 5, 10 |
| 27. | 70 | Eastern MP, Parts of Chattishgarh | 10, 11 |
| 28. | 71 | Parts of Chattishgarh, Jharkhand | 11, 12 |
| 29. | 72 | South Bengal | 15, 12 |
| 30. | 73 | Tripura, Manipur, Mizoram | 15, 17 |
| 31. | 80 | Saurastra region of Gujarat | 5 |
| 32. | 81 | Parts of Gujarat and Maharastra | 5, 19, 6 |
| 33. | 82 | South-western MP and Eastern Maharastra | 6, 10, 5 |
| 34. | 83 | Eastern Maharastra, Parts of Chattishgarh | 10, 11, 12 |
| 35. | 84 | Orissa | 12 |
| 36. | 85 | Coastal Orissa and Coastal WB | 15, 18 |
| 37. | 94 | Western Maharastra | 19, 6 |
| 38. | 95 | Parts of Maharastra, North-western AP, Northern Karnataka | 6 |
| 39. | 96 | Southern Chattishgarh, Northern AP | 7, 12, 6 |
| 40. | 97 | Southern Orissa, Parts of AP | 18, 12 |
| 41. | 107 | Parts of Maharastra, Karnataka and Goa | 19, 6 |
| 42. | 108 | Parts of Karnataka, parts of AP | 6, 7, 3 |
| 43. | 109 | Parts of AP | 7, 18 |
| 44. | 120 | Coastal Karnataka | 19 |
| 45. | 121 | Southern parts of Karnataka, Southern parts of AP | 8, 3, 6, 19 |
| 46. | 122 | Southern parts of AP and Northern TN | 7, 8, 18 |
| 47. | 134 | Northern Kerala and Tamil Nadu | 8, 19 |
| 48. | 135 | Coastal Tamil Nadu | 8, 18 |
| 49. | 147 | Southern Kerala and Southern Tamil Nadu | 8, 18, 19 |

4. **To assess the resource conservation technologies (RCTs) for enhancing carbon sequestration in soil**

A field experiment with soybean-wheat system was conducted for two consecutive years, i.e., 2005-06 and 2006-07 at IISS farm to assess the effect of resource-conserving technologies, like no tillage and residue incorporation practices, on carbon accumulation and to use the data set obtained from this experiment to assess the soil organic matter dynamics. The experiment was set up in a split-plot design replicated three times with tillage treatments as main plot and nutrient/organic matter and their combination as sub-plot treatments in soybean. The wheat crop was cultivated with recommended dose of NPK. Soybean was grown as rainfed, while wheat was grown with 1 pre-sowing plus 3 post-sowing irrigations at crown root initiation, maximum tillering and flowering stages. The treatment details are given in Table 4.1. Soil samples were collected from each plot at three depths, i.e., 0-5, 5-15 and 15-30 cm at the end of two crop cycles. Processed soil samples were used for aggregate analysis. The soil aggregate of size from 4 to 2 mm were wet sieved to separate macro aggregates (>0.25 mm) and micro aggregates (<0.25 mm). Total organic carbon (TOC) was measured (of whole soil) using Analytic Xena TOC Analyzer (Dry combustion method). .

**Table 4.1. Treatment details**

<table>
<tr><th>Main plot</th><th colspan="4">CT : Conventional Tillage<br>NT: No-tillage</th></tr>
<tr><th rowspan="2">Sub-plot</th><th colspan="4">Nutrient management treatment in soybean-wheat</th></tr>
<tr><th colspan="3">Soybean</th><th>Wheat</th></tr>
<tr><td>N1</td><td colspan="3">RDF</td><td>RDF</td></tr>
<tr><td>N2</td><td colspan="3">RDF+5 t FYM (productive)</td><td>RDF</td></tr>
<tr><td>N3</td><td colspan="3">RDF+5 t wheat residues (protective)</td><td>RDF</td></tr>
<tr><td>N4</td><td colspan="3">5 t FYM (productive)</td><td>RDF</td></tr>
<tr><td>N5</td><td colspan="3">5 t wheat residues (protecitve0</td><td>RDF</td></tr>
<tr><th rowspan="2">Crop</th><th colspan="3">Recommended dose of fertilizer (RDF)</th><th rowspan="2">Irrigation</th></tr>
<tr><td>N</td><td>$P_2O_5$</td><td>$K_2O$</td></tr>
<tr><td>Soybean</td><td>30</td><td>60</td><td>30</td><td>Rainfed</td></tr>
<tr><td>Wheat</td><td>100</td><td>50</td><td>30</td><td>4*</td></tr>
</table>

4* = First : Pre-sowing; Second : Crown root initiation; Third: Maximum tillering; Fourth: Flowering stage

In general, per cent macro-aggregate was much higher than micro-aggregates in all treatments, and macro aggregation increased with depth (Fig. 4.1). Tillage treatments had marked effect on aggregation up to a depth of 15 cm, beyond which the effect was negligible. Macro-aggregate percent increased by about 5% under no tillage at 0-5 cm and by about 2% at 5-15 cm depth. Amongst the sub-plot treatments, addition of organic matter, irrespective of

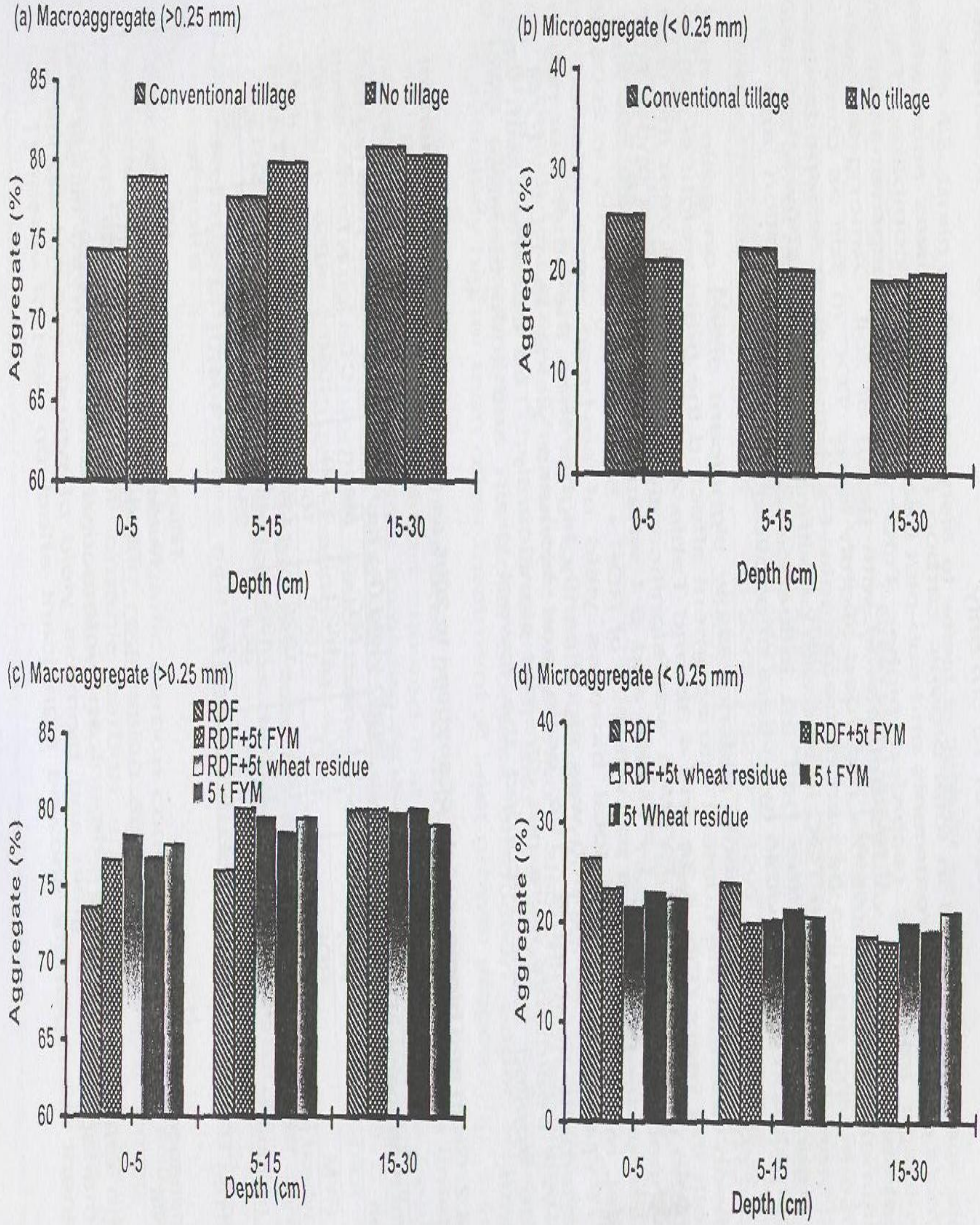



Fig. 4.1. Influence of tillage and nutrient management on soil macro- and micro-aggregates

tillage, increased the per cent macro-aggregates over recommended dose of fertilizer (RDF). All the organic treatments with or without RDF maintained more or less same level of aggregation and the effect of organic treatments was apparent up to a soil depth of 15 cm only.

A similar trend in total organic carbon (TOC) of soil was seen when the effects of main-plot treatments and sub-plot treatments were compared (Fig. 4.2) No-tillage treatments recorded higher TOC values than conventional tillage treatment and TOC values decreased with depth of soil. Among the sub-plot treatments RDF treatments recorded slightly lower TOC in soil as compared to those having organics as part of treatments. FYM and wheat residue treatments had more or less same TOC in soil with or without RDF. This shows that addition of organic matter/residue had an influence on soil aggregation and carbon accumulation in soils within two years of application.

The tillage treatments did not show significant effect on grain weight of soybean whereas the nutrient management affected the grain weight significantly in both the years (Fig. 4.3a and 4.3b and Table 4.2). In the first year the yield of soybean under RDF+5 t FYM/ha was significantly higher than that under RDF + 5 t wheat residue/ha, 5 t FYM/ha and 5 t wheat residue/ha, while the yield of soybean under RDF was at par with that of RDF + 5 t FYM/ha. Similarly in 2006, the highest mean grain and total biomass yield of soybean were obtained with RDF+FYM treatment, which was significantly higher than the other four nutrient management treatments. The grain and biomass yields in RDF, FYM and RDF+WR treatments were not different significantly. The treatment with wheat residue applied alone recorded the lowest grain and total biomass yield of soybean.

**Table 4.2. Grain and biomass yield of soybean in 2006 as affected by tillage and nutrient management**

| Nutrient management treatment | | Grain yield (kg ha$^{-1}$) | | | Biomass yield (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| Soybean | Wheat | CT | NT | Mean | CT | NT | Mean |
| RDF | RDF | 1237 | 1423 | 1330 | 4050 | 4255 | 4152 |
| RDF+5t FYM | RDF | 1683 | 1602 | 1643 | 4540 | 4558 | 4549 |
| RDF+5t wheat residue | RDF | 1363 | 1325 | 1344 | 3950 | 4275 | 4113 |
| 5t FYM | RDF | 1388 | 1433 | 1410 | 4271 | 4301 | 4286 |
| 5t wheat residue | RDF | 1014 | 954 | 984 | 3425 | 3580 | 3503 |
| | Mean | 1337 | 1347 | | 4047 | 4194 | |
| LSD (P<0.05) | | | | | | | |
| Tillage : | NS | | | Tillage : | | NS | |
| Nutrient management : | 185 | | | Nutrient management : | | 311 | |
| Tillage x NM : | NS | | | Tillage x NM : | | NS | |

The effect of tillage treatment and interaction effect between tillage and nutrient management on grain and biomass yield of wheat was not significant while nutrient management showed significant effect on yield of wheat (Table

4.3). Among the nutrient management treatments, grain yield was minimum (3293 kg/ha) in wheat residue treatment followed by RDF (3415 kg/ha) and FYM (3424 kg/ha) treatments. Maximum grain yield (3779 kg/ha) was recorded in RDF+FYM treatment which was significantly more than wheat residue, FYM and RDF treatments. Biomass yield of wheat followed a similar trend.

**Table 4.3. Grain and biomass yield of wheat in 2006-07 as affected by tillage and nutrient management**

| Nutrient management treatment | | Grain yield (kg $ha^{-1}$) | | | Biomass yield (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| Soybean | Wheat | CT | NT | Mean | CT | NT | Mean |
| RDF | RDF | 3336 | 3494 | 3415 | 8416 | 8750 | 8583 |
| RDF+5t FYM | RDF | 3660 | 3898 | 3779 | 9214 | 9517 | 9365 |
| RDF+5t wheat residue | RDF | 3566 | 3718 | 3642 | 8999 | 9088 | 9043 |
| 5t FYM | RDF | 3491 | 3358 | 3424 | 8805 | 8194 | 8500 |
| 5t wheat residue | RDF | 3373 | 3213 | 3293 | 8517 | 8039 | 8278 |
| Mean | | 3485 | 3536 | | 8790 | 8718 | |
| LSD (P<0.05) | | | | | | | |
| Tillage : | NS | | | Tillage : | | NS | |
| Nutrient management : | 225 | | | Nutrient management : | | 623 | |
| Tillage x NM : | NS | | | Tillage x NM : | | NS | |

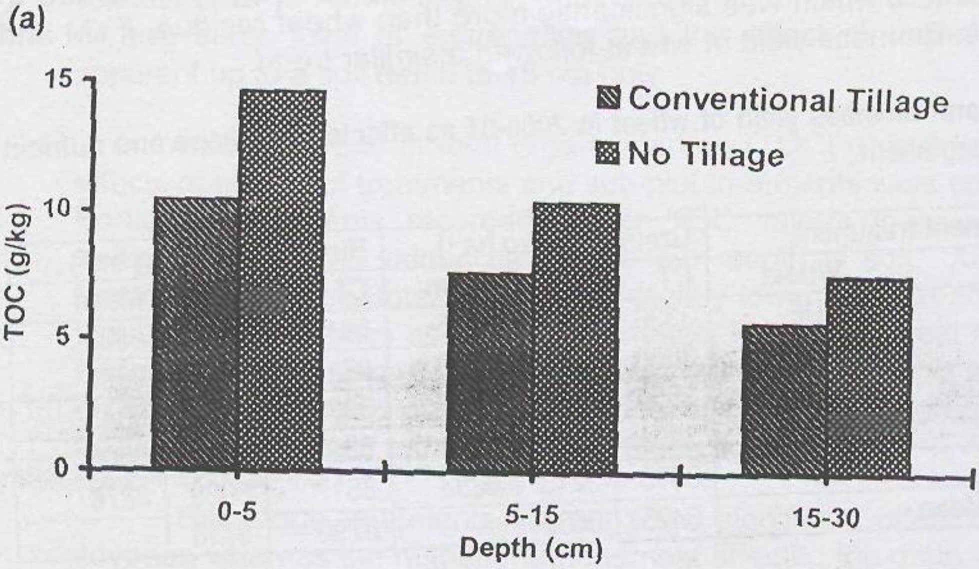
The tillage showed significant effect on LAI of soybean in 2005 at maximum LAI stage. The nutrient management also showed significant effect on LAI (Fig. 4.4a and b). The LAI under RDF and RDF+FYM was significantly higher than other treatments. The total biomass production under RDF+FYM was significantly higher than other treatment at later growth stages (Fig. 4.4c).

In 2006, changes in leaf area index and biomass yield with time during the crop growth period of soybean showed that only wheat residue treatment was inferior to all other treatments involving RDF and FYM. Effect of tillage on leaf area index and biomass yield was not discernible. RDF plus 5 t FYM $ha^{-1}$ maintained higher biomass yield than those with other sub-plot treatments throughout the crop growth period (Fig. 4.5).

## 5. To improve the available models for soil organic matter dynamics by incorporating the relationships derived from this study.

### 5.1. Relationship between soil organic carbon content (g $kg^{-1}$) and texture of soils

The secondary data on soil organic carbon content and texture soil profiles were collected and the simple linear regression analysis was performed to find out relationships between soil organic carbon and clay content, as well as soil organic carbon and silt+clay content. The soil orders were Alfisols, Entisols and



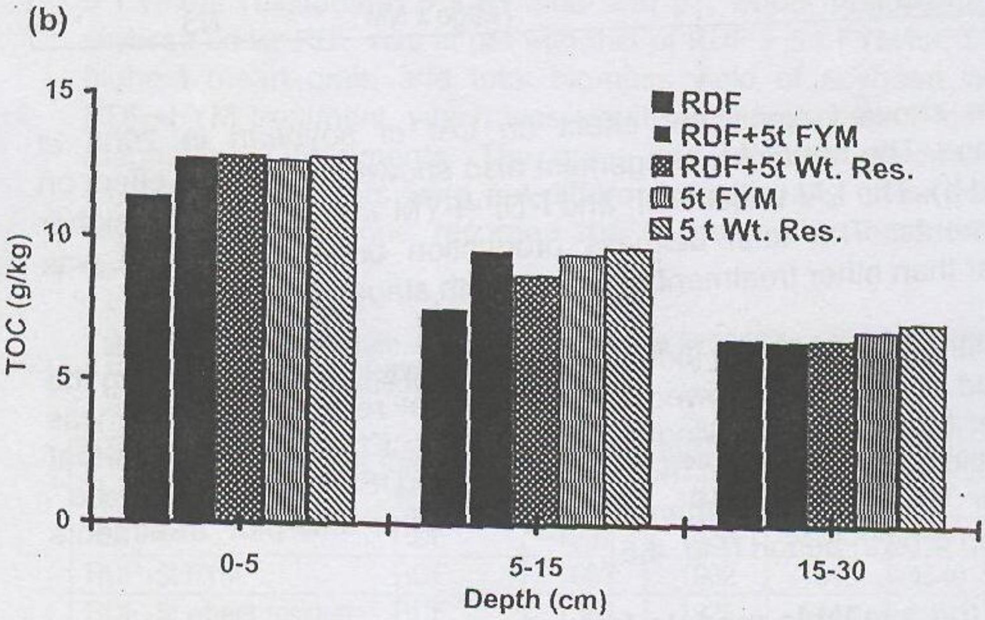




**Fig. 4.2. Influence of tillage and nutrient management on total organic carbon of soil**

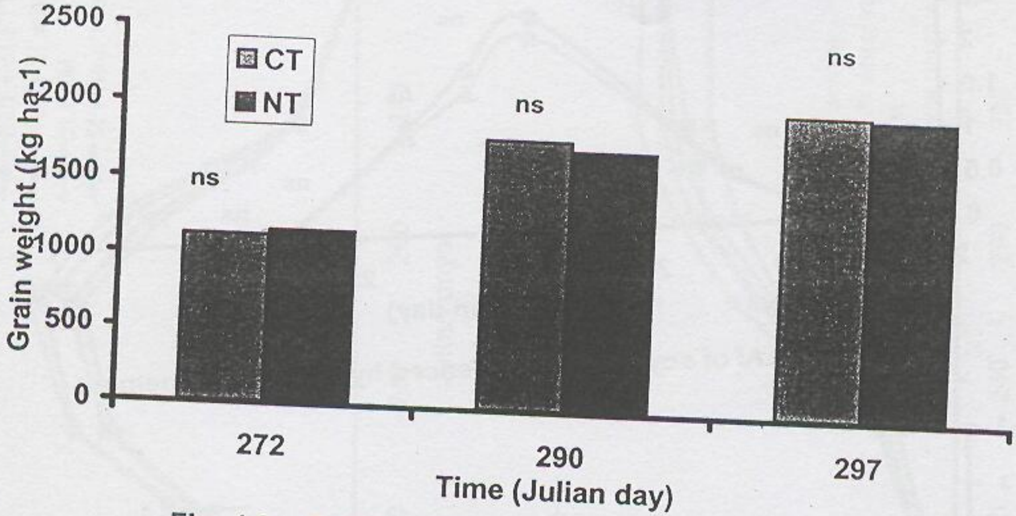



Fig. 4.3a. Grain weight of soybean as affected by tillage management

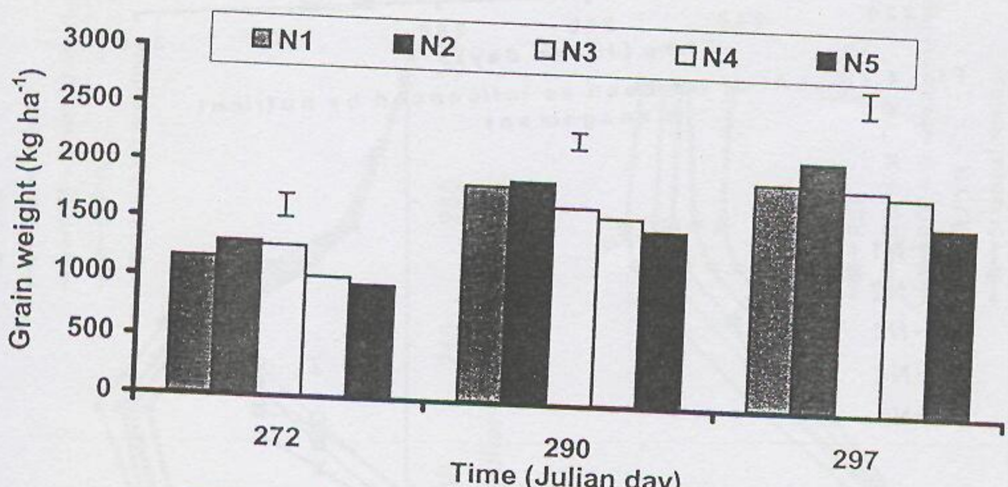



Fig. 4.3b. Grain weight of soybean as influenced by nutrient management

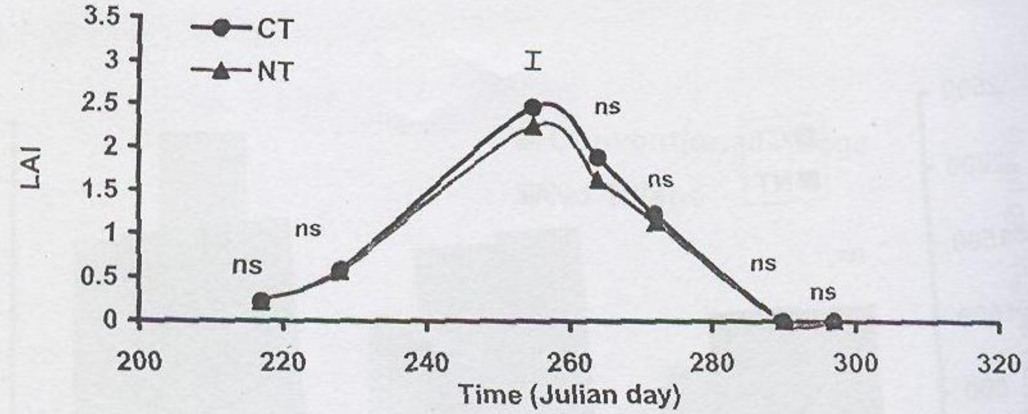



Fig. 4.4a. LAI of soybean as influenced by tillage management

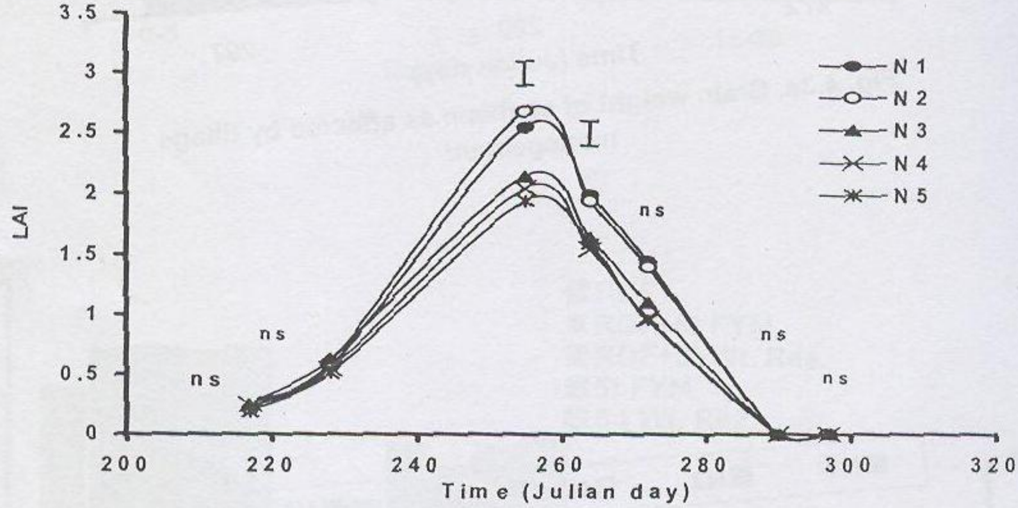



Fig. 4.4b. LAI of soybean as influenced by nutrient management

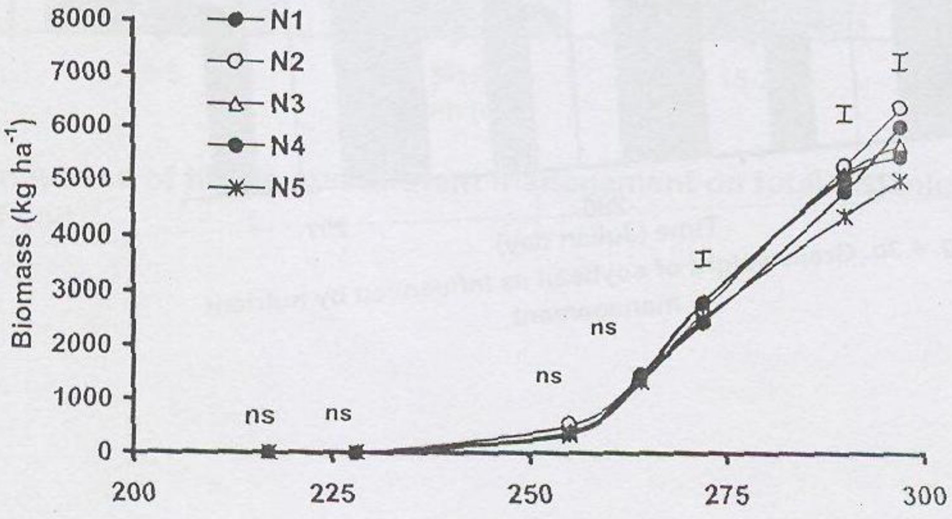



Fig. 4.4 c. Biomass of soybean as influenced by nutrient management

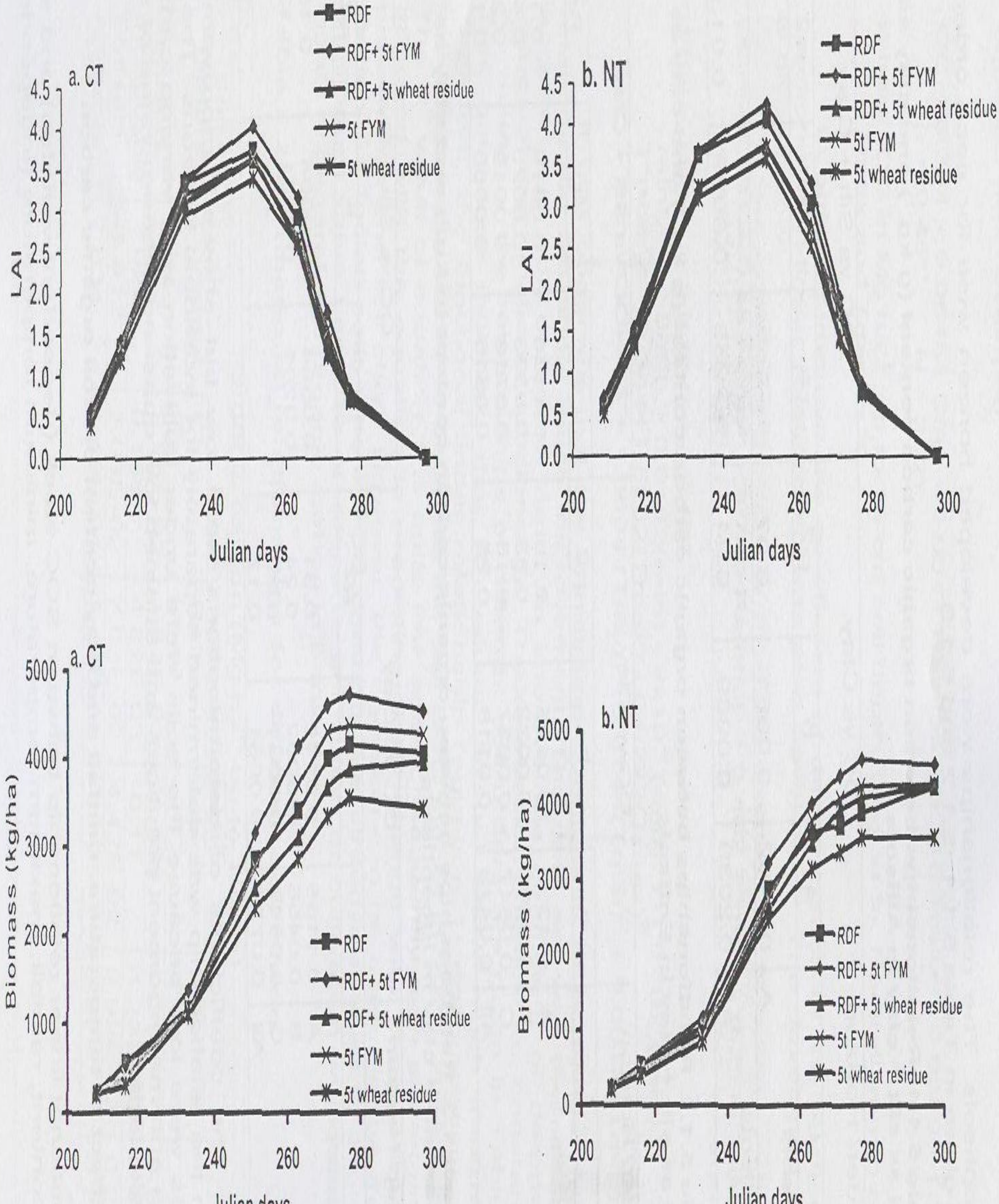



Fig. 4.5. Changes in leaf area index (LAI) and biomass yield of soybean as influenced by nutrient management treatments under conventional (CT) and no tillage (NT) treatment

Inceptisols. The relationships were developed horizon wise for each order and are given in Table 5.1.1, 5.1.2 and 5.1.3.

**Table 5.1.1. Relationships between organic carbon content (g $kg^{-1}$) and clay as well as silt + clay in Alfisols**

| Order/ Horizon | OC vs Clay | | | OC vs Silt + Clay | | |
|---|---|---|---|---|---|---|
| | a | b | $R^2$ | a | b | $R^2$ |
| Alfisols | | | | | | |
| A | 0.3402 | 0.0051 | 0.07 | - | - | - |
| Aridisols | | | | | | |
| All | 0.2039 | 0.0089 | 0.21 | 0.2235 | 0.0089 | 0.013 |

**Table 5.1.2. Relationships between organic carbon content (g $kg^{-1}$) and clay as well as silt + clay in Entisols**

| Order/ Horizon | OC vs Clay | | | OC vs Silt + Clay | | |
|---|---|---|---|---|---|---|
| | a | b | $R^2$ | a | b | $R^2$ |
| Entisols | | | | | | |
| A | 0.1335 | 0.0125 | 0.19 | 0.1134 | 0.0070 | 0.14 |
| B | 0.0460 | 0.0032 | 0.33 | 0.0333 | 0.0025 | 0.41 |
| C | 0.0817 | 0.0037 | 0.15 | 0.0716 | 0.0019 | 0.22 |
| All | 0.0413 | 0.0118 | 0.25 | 0.0616 | 0.0050 | 0.14 |

**Table 5.1.3. Relationships between organic carbon content (g $kg^{-1}$) and clay as well as silt + clay in Inceptisols**

| Order/ Horizon | OC vs Clay | | | OC vs Silt + Clay | | |
|---|---|---|---|---|---|---|
| | a | b | $R^2$ | a | b | $R^2$ |
| Inceptisols | | | | | | |
| A | 0.1165 | 0.0112 | 0.31 | 0.0594 | 0.0064 | 0.18 |
| B | 0.0456 | 0.0052 | 0.24 | 0.0201 | 0.0031 | 0.13 |
| C | 0.0647 | 0.0031 | 0.29 | - | - | - |
| All | 0.0776 | 0.0061 | 0.17 | - | - | - |

The coefficients of determinations were low but showed improvement when the relationship was determined separately for individual horizons. The $R^2$ values were low because the soils were under cultivation with varying carbon inputs and management practices and attained low quasi-equilibrium value of soil organic carbon.

## 5.2. Effect of temperature, rainfall and clay content on soil organic carbon

A functional linear relationship between SOC stock (dependent variable) and soil clay content, rainfall, maximum temperature, minimum temperature (independent variables) was developed using multiple linear regression analysis. The following equation was developed:

OC = 6.364 + 0.06451 Clay + 0.0041 Rainfall – 0.116 Tmax + 0.05896 Tmin
(r = 0.45**, N = 252) ------------- **equation 1**

Where, OC in Mg $ha^{-1}$ up to 15 cm soil depth, Clay in %, Rainfall in mm and Tmax and Tmin in $^{o}C$

In order to improve the co-efficient of determination of the relationship, a functional non-linear relationship was also developed. The developed equation is given below:

OC = -4.181 + 0.483 Clay* + 0.746 Rainfall* + 0.462 T*max - 0.211T*min
r = 0.50**, N = 252) ------------- **equation 2**

Where, clay* $= 2.0321(clay)^{0.4267}$
rain* $= 0.5908 + 0.0162(rain) - 8x10^{-6} (rain)^2 + 1.6x10^{-9}(rain)^3$
T*max $= -10.344+1.5262(Tmax) - 0.0272(Tmax)^2$
T*min $= 2.1628 + 1.3694 (Tmin) - 0.0744(Tmin)^2 + 0.0012 (Tmin)^3$

It was observed that the correlation coefficients of non-linear functional relations did not show much improvement. The data set was then rearranged according to soil orders in order to improve the coefficient of determination values of the functional relationship. The regression coefficients, constants, and $R^2$ values of the relationships of different soil orders are given in Table 5.2.1. This data also indicated that $R^2$ values did not show much improvement. Therefore, the functional linear relationship (equation 1) encompassing all the soil types was utilized to estimate the soil SOC stocks in 2020, 2050 and 2080. The $R^2$ value of equation 1 is quite low and consequently high uncertainty was attached with the equation in predicting SOC change with change in climate parameters and soil clay. However, the equation can be useful in the available models for Indian soils where SOC contents are already reduced to a low quasi equilibrium value because of intensive cultivation or cultivation with inadequate inputs in general and organic carbon in particular.

**Table 5.2.1. Functional relationships for different soil orders**

| Organic carbon (Mg $ha^{-1}$ up to 15 cm) | | | | | | |
|---|---|---|---|---|---|---|
| Soil Orders | Regression coefficients | | | | | $R^2$ |
| | Constant | Clay (%) | Rain (mm) | Max T ($^oC$) | Min T ($^oC$) | |
| Vertisols | 5.372 | 2.26E-02 | 1.62E-03 | -0.124 | 0.254 | 0.097 |
| Inceptisols | 3.029 | 0.158 | 4.82E-03 | -0.11 | 4.23E-03 | 0.430 |
| Entisols | -1.812 | 7.03E-02 | 7.03E-02 | 4.42E-02 | 9.99E-02 | 0.259 |
| Aridisols | 7.034 | 1.49E-01 | 1.49E-01 | -0.175 | 0.229 | 0.252 |

*Pedo-transfer function was used to estimate BD (Tomasella and Hodnet, 1998), where BD data was missing for calculating soil organic carbon stocks*

### 5.3. Relationship between aggregate carbon content (%) and aggregate (%) of soils

A significant positive correlation between macro-aggregates and its carbon content was found:

% Macro-aggregate-C = 0.007 (% macro-aggregate) + 0.3845
(r = 0.67** ) -----------equation 3

whereas, a significant negative correlation was found between micro-aggregate and its carbon content. The equation is given below:

% Micro-aggregate-C = -0.0026 (% micro-aggregate) + 0.5114
(r = 0.46**) ------------ equation 4

A significant positive correlation between soil organic carbon content and water stable aggregates,
% SOC = 0.0109 (% water stable aggregates) - 0.0105
(r = 0.92**) ---------- equation 5

as well as mean weight diameter

% SOC = 0.753 MWD + 0.04
(r = 0.87**) ---------- equation 6

were found showing that increase in SOC content was associated with higher size aggregate formation with greater water stable aggregates.

These relationships can be used in predicting soil structural stability in available models in order to compare different management practices where soil organic matters vary.

# Central Soil and Water Conservation Research and Training Institute - Dehradun

**Study locations**

Seven watersheds (1. Almas, Tehri Garhwal, Uttaranchal ; 2. Umiam, Meghalaya ; 3. Udhagamanadalam, Nilgiris, Tmailnadu; 4. Pogalur, Coimbatore, Tmailnadu ; 5. Jonainala ,Keonjhar, Orissa ; 6. Belura, Akola, Mahrashtra ; and 7. Antisar, Kehda, Gujarat) located in different agro-ecological regions of the country and having area ranging between 491 ha (Pogalur, Coimbatore, Tamilnadu) to 816 ha (Jonainala, Keonjhargarh, Orissa) has been selected for study (Table 1).

**Rainfall**

**Analysis of historical rainfall data**

Analysis of long term historical rainfall time series data of 8 watersheds representing different agro ecological regions of the country and of 12 districts of Punjab reveals that though the annual rainfall shows a increasing trend in plain areas viz; Keonghargarh in eastern ghat of Orissa, Buldana in Maharashtra, Kheda & Anand in Gujarat, Coimbatore in Tamil Nadu and in Patiala and Kapurthala of Punjab but it is not significant. The decreasing trend is observed in mountainous/hilly regions i.e.Tehri & Dhanaulati in northern Himalayas and Udhagamandalam in Nilgiris. Decreasing trend is also observed in all the districts of Punjab except Patiala and Kapurthala **(Table 2-3).**

Based on above it can be concluded that the state of Punjab, northern Himalayas and Upper Nilgiris (mountainous and hilly region) have decreasing trend of rainfall whereas Kheda area of Gujarat, Keonjhagarh in Orissa and, Coimbatore area in Tamil Nadu have a increasing trend of rainfall.

**Retrieval of projected rainfall data from IPCC/IITM, Pune and its analysis**

Projected rainfall data as assessed by 7 different General Circulation Model (GCM) for different durations at specified spatial resolution are available on IPCC. The data are available for base period of 1961-1990, 2011-2040, 2041-2070 and 2071-2100. Monthly projected rainfall data were retrieved. However, none of the 7 GCM models except HADCM3 could provide proper and continuous data for A2a scenario.

- Thus, the projected rainfall data for A2a scenario (available at 2.50 x 3.80) spatial resolution of HADCM3 has been retrieved and used in the study (Table 4).
- The simulated (1961-1990) and projected (2071-2100) rainfall of 7 watersheds representing different agro ecological regions of the country viz. Almas, Antisar, Belura, Joaninala, KG4, Pogalur and Umiam has also been retrieved from RCM of IITM, Pune (PRECIS; generated from GCM of HADCM3 for A2a Scenario) and analysed for monthly, seasonal and annual rainfall and rainy days as daily rainfall data are available for this duration only (Table 5-6).
- Projected monthly rainfall data for above 7 watersheds for the period of 2011-2040 and 2041-2070 have also been retrieved from IPCC websites for A2a scenario from GCM of HADCM3 as these do not provide daily rainfall. The rainfall erosivity factor 'R' has been computed for 1961-90 and for projected rainfall of 2011-2040, 2041-2070 and 2071-2100 duration using the empirical model developed by Ram Babu et al., (2004) which has been found more realistic than other models in vogue.
- Sensitivity analysis of soil erodibility factor 'K' for use in USLE for computation of soil loss

- The sensitivity analysis of soil erodibility factor 'K' of Universal Soil Loss Equation (USLE) to be used for computing projected soil loss with respect to organic matter has also been carried out. Insignificant effect over soil erodibility factor 'K' has been observed with expected change of organic matter due to change of temperature and rainfall (Fig 1).
- Relation ship between crop cover and management practices factor 'C' and support practice factor 'P' with annual rainfall for use in USLE for computation of soil loss
- The review and compilation of information on crop cover and management practices factor 'C' and support practice factor 'P' available in India of USLE were also completed. The relationship between rainfall and crop cover and management practices factor 'C' and supportive factor 'P' revealed a good relationship for crop cover and management practices factor 'C' ($R^2$=0.94; Fig 2) but poor relationship between annual rainfall and support practice factor 'P' ($R^2$=0.31; Fig 3). The crop cover and management practices factor 'C' decreases with increase of annual rainfall.

**Crop productivity and rainfall**

- Trend analysis of productivity of different crops of various districts of Punjab
- The trend analysis of the productivity of four different crops, viz. wheat, maize, sugarcane and rice for the 12 districts of Punjab for a period of 34 years (1970-71-2003-04) has been done .The analysis reveals that almost all the districts show increasing trend in the productivity of wheat. The highest increase has been observed in Patiala, Sangrur and Kapurthala (90 to 82 kg $ha^1$ $yr^1$) and lowest increase has been observed in Ludhiana, Ropar and Hoshiarpur (67 to 64 kg $ha^1$ $yr^1$).

Trend analysis of productivity of maize shows increasing trend in the districts of Jalandhar, Kapurthala, Bhatinda, Hoshiarpur, Amritsar, and Gurudaspur. In the districts viz. Roper, Patiala, Sangrur and Ludhiana, the increasing trend is observed only after 1980 and before that it has fluctuating trend. Only in Hoshiarpur decreasing trend in productivity has been observed.

In the case of sugarcane crop, only in three districts (Amritsar followed by Sangrur and Patiala) of Punjab, the increasing trend is observed in the productivity. In most of the other districts, the increasing trend is observed upto 1990 of study period, afterwards it starts showing decreasing trend for rest of the years. In few districts viz. Gurudaspur, Bhatinda. Faridkot and Ludhiana, trend has been initially increasing moderately (upto 2000) then becoming almost constant over rest of the years.

The increasing trend of productivity of rice has been observed only in Firozpur, Hoshiarpur, Gurudaspur and Amritsar. In other districts, the productivity appears to be reaching to the saturation except in Faridkot where a decreasing is observed.

**Relationship between NYD of various crops and rainfall deviation of various districts of Punjab**

**Wheat**

Non-significant trend has been observed between normalized yield deviation (NYD) and rabi rainfall deviation (1970-71 to 2003-04) for wheat productivity in 12 districts of Punjab. In four districts viz. Hoshiarpur, Ferozpur, Ropar and Sangrur, NYD has been observed increasing with increase of rabi rainfall (maximum in Hoshiarpur). However, in other districts NYD is decreasing with increase in rabi rainfall deviation.

**Rice**

The trend analysis between NYD and kharif rainfall deviation for rice productivity in 12 districts of Punjab show mixed trends and the relation is not significant. In the districts of Hoshiarpur and Gurudaspur, followed by Firozpur and Amritsar, no change has been observed in the NYD with the increase in kharif rainfall deviation. In few districts viz. Kapurthala, Ludhiana and Jalandhar the NYD has been found to be decreasing with increase of Kharif rainfall deviation. However, in rest of the districts, the NYD is increasing with increase of kharif rainfall deviation (Ropar, Faridkot, Sangrur, Bhatinda and Patiala.

**Sugarcane**

The relationship between NYD and annual rainfall deviation for sugarcane productivity for seven districts also shows mixed trend and is non significant .In three districts, viz. Sangrur, Ferozpur and Patiala an increasing trend of NYD with increase of annual rainfall deviation (maximum in Sangrur) is observed. In other three districts viz. in Ludhiana, Ropar, and Faridkot the NYD is becoming almost constant with increase in annual rainfall. Only in Bhatinda, NYD is moderately decreasing with increase in annual rainfall deviation.

**Maize**

The NYD of Maize is observed to be non significant with kharif rainfall deviation in the district of Bhatinda, Sangrur, Kapurthala and Ferozpur, whereas it has poor relationship at Jalandhar, Amritsar, Hoshiarpur, Ludhiana, Patiala, Ropar, Gurdaspur and Ferozpur.

- Based on above analysis it can be concluded that in the state of Punjab, though the annual rainfall is very less in all the 12 districts under study (it varies between 275.90 mm (Bhatinda) to 978.30 mm (Gurudaspur), there is no significant relationship of productivity of rice, wheat and sugarcane with annual, kharif or rabi rainfall deviation. How ever in case of maize it has.
- Workshop on "Assessing impact of climate change on water resources"
- Three days Workshop on "Assessing impact of climate change on water resources" was organized at CSWCRTI, Dehradun during Feb 27th – March 1st, 2006 in which 26 scientists, professors and experts from NIH Roorkee and IIRS, Dehradun participated.

**Computation of projected runoff**

The soil conservation service (SCS) method making use of curve number was used to compute/assess runoff. The curve number was obtained from standard tables available in literature. The related factors viz. crops and their management, soils and hydrological condition were obtained from soil layers developed as stated above.

The runoff for the base period of 1961-1990 and for the projected period of 2071-2100 has been assessed under 3 options as detailed below.

**Option l:** The existing system of management and cultivation continues irrespective of rainfall.

**Option II:** The economic and social condition of farmers shall not allow them to practice better improved management and cultivation practices hence the condition shall deteriorate irrespective of rainfall.

**Option III:** The technological advancement and social – economic improvement shall help the farmer to adopt better management and cultivation as per changed rainfall**.**

The change in area, land management, hydrological condition and thus the relevant curve number were arrived in a rational manner by adopting the law of expected acceptance. A sample of such exercise is presented in Table no. 7 for Jonainala watershed.

**Runoff projections**

Seasonal and annual runoff for all the 7 watersheds has been computed for 2071-2100 under three different options. The runoff at Pogalur is expected to increase by 6 to 12 times during 2071-2100 than that of 1961-1990. The runoff at Jonainala is projected to increase between 83 to 111 percent and at Belura between 142 to 182 per cent in comparison to the runoff of 1961-1990. The runoff at Antisar is assessed to increase between 117 -227 percent during 2071-2100 than that of 1961-1990. The runoff at Almas, Umiam and Udhagamandalam is expected to increase by 56 to 132, 96 to 171 and 94 to 309 percent than the runoff available during 1961-90. Most of the increase in runoff has been observed during monsoon season (Table 8-11 and Fig 4-7).

**Drought and Flood analysis**

The runoff data of 1961-1990 and 2071 to 2100 for all the seven watersheds has been computed and analyzed for the frequency of drought and flood. The number of years with runoff less than 50 mm, 50-150 mm, 150-300 mm and more than 300 mm has been grouped and deviation has been computed for 1961-1990 to 2071-2100. It is observed that Jonainala and Antisar are going to have doubled flood with more than 300 mm runoff between these two periods. Similarly, Umiam and Belura are also expected to have increased runoff of more than 300 mm by 26 and 151 per cent respectively. Umiam is expected to have more than 300 mm runoff events of 29 again the 23 thus having increase of 23 per cent. At Antisar, which had 13 events during 1961-1990 of less than 50 mm runoff, is going to have only four during 2100. Similarly the runoff events of more than 150 mm which are nil during 1961-90 is going to be eight during 1991-1990. It is thus concluded that during the end of the 21st century though higher rainfall is expected but that shall lead to a wet conditions in almost all the study watersheds except at Udhamagamandalam and Almas (Table 12).

**Computation of projected runoff Soil loss**

**Analysis of rainfall erosivity factor 'R'**

The rainfall erosivity factor 'R' has been observed to increase by 2.9 percent (KG4 Udhangamandam, Nilgiris) to 30.5 percent (Umiam, Meghalaya) between 1961-90 and 2071-2100 for the rainfall generated from RCM of IITM, Pune run under HADCM3 (Table13). However, as the daily rainfall for 2011-2040 and 2041-2070 are not available at IITM, Pune hence the monthly rainfall for this duration was retrieved from HADCM3 GCM for the study watersheds. The 'R' values are projected to increase at all the study locations except at Pogalur where it is expected to decrease by 4.9 per cent between 1961-90 and 2071-2100. The rainfall retrieved from HADCM3 GCM are lower than the IITM, Pune RCM and so the value of 'R'.

**Soil loss projections**

The AVSWAT model has been used to assess soil loss from various watersheds. The model has been calibrated and validated for annual soil loss observed from Almas watershed with $R^2$ value of 0.97. It is observed that Pogalur watershed is going to experience maximum soil loss (757 percent more) followed by Belura watershed (269 percent more), Umiam watershed (71 percent more), Antisar watershed (60 per cent more), Almas watershed (41 percent more), Jonainala watershed (29 per cent more) and least from Udhagamandalam watershed (4 per cent more) during 2071-2100 than that of 1961-1990. The Umiam watershed may yield soil loss of about 24.8 t $ha^{-1}$ $yr^{-1}$ during 2071-2010 than the soil loss of 14.5 t $ha^{-1}$ $yr^{-1}$ observed during 1961-1990. The Poglur watershed is having insignificant soil loss of 7 kg $ha^{-1}$ $yr^{-1}$ during 1961-1990. However, the soil loss in this area is going to increase to 60 kg $ha^{-1}$ $yr^{-1}$ and this loss is going to be detrimental from crop production point of view as this zone is having shallow soil depth and low productivity (Table 14 and Fig 6-7).

**Relationship between crop productivity linked land value and climatological data in Uttarakhand**

The relationship between crop productivity linked land value and rainfall of 5 districts of Uttarakhand viz; Dehradun, Tehri Garhwal (Garhwal region), Almora, Nainital (Kumaun region) and Udham Singh Nagar (Foot hills) have been developed and it has been observed that a good correlation exists between July rainfall and market (sale value) and agriculture value (lease value) of land ($R^2$ = 0.83) followed by the relationship between annual rainfall and market and agriculture value of land ($R^2$ = 0.73) and between *kharif* rainfall and market and agriculture value of land ($R^2$ = 0.72). The highest agriculture value (lease value) of irrigated land has been observed at Udham Singh Nagar with a value of Rs. 40,450.00 per ha followed by Rs. 24,670.00 per ha in Dehradun and Rs. 16,800.00 per ha in Tehri Garhwal. The highest agriculture value of rainfed land has been observed in Dehradun with a value of Rs. 17,878.00 per ha followed by Rs. 13,367.00 per ha in Tehri Garhwal lowest of Rs. 7,533.00 per ha in Almora. Similar trend has been observed for market value of land as well (Table 15).

**Table: 1. Details of the watersheds under study**

| S.N. | Name of the watershed | Longitude, Latitude | Agro ecological Zones (Planning Commission) | Geographical Location | Area (ha) |
|---|---|---|---|---|---|
| 1 | Almas, Thyathud, Dhanolty, Tehri Garhwal, Uttaranchal | 78°10'- 78°13' E, 30°25'- 30°30' N | Western Himalayan Region | North Himalaya | 536 |
| 2 | Jonainala, Keonjhar, Orrisa | 85°48'-85°50' E, 21°40'-21°45' N | Eastern Plateau and Hills Region | Eastern Ghat | 816 |
| 3 | Belura, Akola, Maharastra | 76°51'-76°57' E, 20°31'- 20°34' N | Western Plateau and Hills Region | **Tropical** low rainfall | 636 |
| 4 | Mawpun, Umiam, Meghlaya | 91°54'-91°57' E, 25°40'- 25°43' N | Eastern Himalayan Region | North Eastern Region | 800 |
| 5 | Udhgamandalam, Nilgiris, Tamilnadu | 76°38'-76°40' E, 11°21'- 11°24' N | Southern Plateau and Hills Region, Wet area | Western Ghat | 638 |
| 6 | Pogalur ,Coimbatore, Tamilnadu | 77°2'- 77°4' E, 11°12'-11°16' N | Southern Plateau and Hills Region, Dry area | Tropical low rainfall in Peninsular India | 491 |
| 7 | Antisar ,Kheda, Gujrat | 73°10' - 73°12' E 23°O' - 230 01' N | Gujarat Plains & Hills Region | North West India | 599 |

**Table: 2. Trend indications of Annual and Monsoonal rainfall of 12 districts of Punjab**

| S.l. | Name of the districts | Parameter /Index | |
|---|---|---|---|
| | | **Annual Rainfal (mm)** | **Seasonal Rainfall-Monsoon (mm)** |
| 1. | Gurudaspur | - | - |
| 2. | Amritsar | - | - |
| 3. | Kapurthala | + | + |
| 4. | Jallandhar | - | - |
| 5. | Hoshiarpur | - | - |
| 6. | Roper | - | - |
| 7. | Ludhiana | - | - |
| 8. | Firozpur | - | - |
| 9. | Faridkot | - | - |
| 10. | Bhatinda | - | - |
| 11. | Sangrur | - | - |
| 12. | Patiala | + | + |

- Decreasing Trend; + Increasing Trend

**Table: 3. Trend indications of various rainfall characteristics of selected stations**

| S.l. | Parameter /Index | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Keonjhargarh | Buldana | Tehri | Udhagamandalm | Kheda | Dhanolti | Coimbatore | Antisar |
| 1. | Annual Rainfall | + | + | - | - | + | - | + | - |
| 2. | Seasonal Rainfall (Monsoon) | - | - | - | - | + | - | + | - |
| 3. | One day Maximum Rainfall | + | + | - | - | + | - | + | + |
| 4. | Occurrence of one day max rainfall in Julian Days | - | - | - | - | + | - | + | + |
| 5. | Annual Rainy Days | + | + | + | - | - | - | + | - |
| 6. | Rainy Days during Monsoon Season | + | + | + | - | - | - | + | - |
| 7. | Annual Dry Days (with zero rainfall) | - | - | - | - | + | - | - | - |
| 8. | Continuous dry spell during monsoon Season | - | - | - | - | + | - | + | + |
| 9. | Shift in monsoon season from Jun-Sep to Jul-Oct | - | - | - | - | + | - | + | - |
| 10. | 3 years moving average of annual rainfall | + | + | - | - | + | - | + | - |
| 11. | 5 years moving average of annual rainfall | + | + | - | - | - | - | + | - |
| 12. | 10 years moving average of annual rainfall | + | + | - | - | + | - | + | - |
| 13. | 15 years segmental study of Annual Rainfall | +<br>+<br>+ | -<br>+<br>+ | -<br>- | -<br>-<br>+ | -<br>- | -<br>- | + | -<br>-<br>- |
| 14. | Monsoon Rainfall/ Annual Rainfall | - | - | + | - | - | - | + | - |
| 15. | Monsoon rainy days/ Annual Rainy Days | - | + | - | + | - | + | - | - |
| 16. | Days with zero rainfall/ Annual Rainfall | - | - | + | + | + | + | - | + |
| 17. | Cumulative Standardized Departure | | | | | | | | |

**- Decreasing Trend; + Increasing Trend**

**Table: 4.** Variations in annual rainfall (mm) retrieved from GCM (HADCM3) & RCM (PRECIS) of A2a scenario of the study watersheds for the period from 1961-90 to 2071-2100

| **Period** | **Watershed Location** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Almas** | **Antisar** | **Belura** | **Jonainala** | **Ooty** | **Pogalur** | **Umiam** |
| **Annual Rainfall (mm)** | | | | | | | |
| **Observed, IMD, Pune** | 1494.0 | 830.0 | 853.0 | 1314.0 | 1058.0 | 662.0 | 2415.3 |
| **1961-1990(RCM)** | 1629.9 | 1148.3 | 1063.6 | 1946 | 1472.1 | 294.8 | 2974.6 |
| **1961-1990(GCM)** | 874.0 | 1095.4 | 1165.6 | 1360.0 | 2030.5 | 2000.5 | 1895.0 |
| **2011-2040(GCM)** | 936.9 | 1135.3 | 1109.1 | 1402.7 | 1965.6 | 2019.0 | 1852.7 |
| **2041-2070(GCM)** | 1061.9 | 1129.2 | 1142.7 | 1462.6 | 1877.4 | 1874.5 | 2124.7 |
| **2071-2100(GCM)** | 1256.1 | 1184.3 | 1240.1 | 1613.1 | 1970.4 | 1890.7 | 2322.8 |
| **2071-2100(RCM)** | 1923.2 | 1359.9 | 1530.5 | 2390.1 | 1522.6 | 338.1 | 4371.1 |

**Table: 5.** Change (percent) in seasonal rainfall (mm) of different watersheds located in different agro- ecological regions of India for A2a scenario (PRECIS, IITM, Pune) during 1961-1990 and 2071-2100

| Season | | Watersheds | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Almas | Antisar | Belura | Jonainala | Ooty | Pogalur | Umiam |
| Winter Monsoon | 1961-90 | 107.6 | 1.3 | 9.2 | 49.2 | 45.2 | 8.6 | 71.9 |
| | 2071-2100 | 90.4 | 4.9 | 13 | 72.2 | 62 | 13 | 94.5 |
| | % Dev. | -16.0 | 276.9 | 41.3 | 46.7 | 37.2 | 51.2 | 31.4 |
| Pre-Monsoon | 1961-90 | 166.6 | 20.7 | 36.3 | 263.3 | 350.4 | 97.4 | 1505 |
| | 2071-2100 | 216 | 32.9 | 60.7 | 322.5 | 364.3 | 120.9 | 2564.6 |
| | % Dev. | 29.7 | 58.9 | 67.2 | 22.5 | 4.0 | 24.1 | 70.4 |
| Monsoon | 1961-90 | 1184 | 1056.5 | 934.5 | 1387.7 | 811 | 68.6 | 1069.6 |
| | 2071-2100 | 1458 | 1257.8 | 1329 | 1675.3 | 738.9 | 61.7 | 1390.5 |
| | % Dev. | 23.1 | 19.1 | 42.2 | 20.7 | -8.9 | -10.1 | 30.0 |
| Post-Monsoon | 1961-90 | 171.9 | 69.7 | 83.6 | 245.7 | 265.5 | 120.3 | 328.1 |
| | 2071-2100 | 158.8 | 64.5 | 128 | 319.9 | 357.6 | 142.7 | 321.5 |
| | % Dev. | -7.6 | -7.5 | 53.1 | 30.2 | 34.7 | 18.6 | -2.0 |
| Annual | 1961-90 | 1629.9 | 1148.3 | 1063.6 | 1946.0 | 6472.1 | 294.8 | 2974.6 |
| | 2071-2100 | 1923.2 | 1359.9 | 1530.5 | 2390.1 | 1522.6 | 338.1 | 4371.1 |
| | % Dev. | 18.0 | 18.4 | 43.9 | 22.8 | 3.4 | 14.7 | 46.9 |

**Table: 6.** Change in seasonal rainy days of different watersheds located in different agro ecological regions of India for A2a scenario (PRECIS, IITM, Pune) during 1961-1990 and 2071- 2100

| Season | | Watersheds | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Almas** | **Antisar** | **Belura** | **Jonainala** | **Ooty** | **Pogalur** | **Umiam** |
| **Winter Monsoon** | 1961-90 | 6 | 0 | 2 | 4 | 5 | 0 | 5 |
| | 2071-2100 | 6 | 0 | 2 | 6 | 6 | 1 | 7 |
| | % Dev. | 0.0 | 0.0 | 0.0 | 50.0 | 20.0 | 0.0 | 40.0 |
| **Pre-Monsoon** | 1961-90 | 16 | 1 | 2 | 17 | 38 | 14 | 53 |
| | 2071-2100 | 20 | 2 | 6 | 26 | 40 | 19 | 60 |
| | % Dev. | 25.0 | 100.0 | 200.0 | 52.9 | 5.3 | 35.7 | 13.2 |
| **Monsoon** | 1961-90 | 85 | 86 | 35 | 103 | 81 | 7 | 96 |
| | 2071-2100 | 84 | 80 | 67 | 96 | 68 | 7 | 88 |
| | % Dev. | -1.2 | -7.0 | 91.4 | -6.8 | -16.0 | 0.0 | -8.3 |
| **Post-Monsoon** | 1961-90 | 7 | 7 | 6 | 18 | 31 | 16 | 26 |
| | 2071-2100 | 7 | 8 | 9 | 20 | 32 | 16 | 21 |
| | % Dev. | 0.0 | 14.3 | 50.0 | 11.1 | 3.2 | 0.0 | -19.2 |
| **Annual** | 1961-90 | 112 | 94 | 45 | 141 | 155 | 38 | 180 |
| | 2071-2100 | 117 | 88 | 84 | 148 | 147 | 43 | 175 |
| | % Dev. | 4.5 | -6.4 | 86.7 | 5.0 | -5.2 | 13.2 | -2.8 |

**Table: 7. Assessment of curve numbers for various options of Jonainala watershed**

| S.No | Land use with management practices (Jonainala watershed) | Soil group | Curve numbers (with area in ha) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Option I | | Option II | | Option III | |
| | | | CN | Area | CN | Area | CN | Area |
| 1. | Forest (Woods - grass combination, orchard or tree farm, Fair) | B | 60 | 502.8 | 60 | 400.0 | 55 | 356.0 |
| 2. | Agriculture (Row crops, Contoured and terraced, Good) | B | 71 | 268.6 | 74 | 345.0 | 70 | 400.0 |
| 3. | Grassland (Pasture, grassland, or range - continuous forage for grazing, Good) | B | 61 | 25.5 | 69 | 35.5 | 61 | 30.0 |
| 4. | Barren Land (Fallow, Crop residue cover, Good) | B | 83 | 19.1 | 85 | 35.5 | 85 | 10.0 |
| Weighted CN and Total area | | | 64 | 816.0 | 67 | 816.0 | 62 | 816.0 |

**Table: 8.** Change in seasonal runoff(mm) under option I of different watersheds located in different agro ecological regions of India for A2a scenario (PRECIS, IITM, Pune) during 1961-1990 and 2071- 2100

| Season | | Watersheds | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Almas | Antisar | Belura | Jonainala | Ooty | Pogalur | Umiam |
| Winter Monsoon | 1961-90 | 1 | 0 | 0.3 | 0.2 | 0.0 | 0 | 3.2 |
| | 2071-2100 | 0.9 | 0.0 | 0.1 | 2.8 | 0.7 | 0 | 8.2 |
| | % Dev. | -10.0 | 0 | -66.7 | 1300.0 | 70 | 0.0 | 156.3 |
| Pre-Monsoon | 1961-90 | 1.0 | 1.8 | 1.5 | 34.3 | 4.7 | 0 | 496.7 |
| | 2071-2100 | 2.0 | 2.12 | 5.3 | 50.2 | 2.2 | 0.8 | 1119.9 |
| | % Dev. | 100.0 | 16.7 | 253.3 | 46.4 | -53 | 80.0 | 417.4 |
| Monsoon | 1961-90 | 79.6 | 53.9 | 213.6 | 162.4 | 13.2 | 0.2 | 94.5 |
| | 2071-2100 | 129.1 | 121.8 | 500.7 | 300.3 | 19.6 | 0.9 | 254.1 |
| | % Dev. | 62.2 | 556.2 | 134.4 | 84.9 | 48 | 350.0 | 1257.8 |
| Post-Monsoon | 1961-90 | 15.0 | 2.1 | 6.9 | 17.5 | 1.9 | 0.7 | 41 |
| | 2071-2100 | 18.6 | 5.7 | 30.8 | 39.0 | 21.2 | 10.1 | 47.4 |
| | % Dev. | 24.0 | 1225 | 346.4 | 122.9 | 1016 | 1342.9 | 2103.4 |
| Annual | 1961-90 | 96.6 | 57.8 | 222.3 | 214.4 | 19.8 | 0.9 | 635.6 |
| | 2071-2100 | 150.6 | 129.6 | 536.9 | 392.3 | 43.3 | 11.8 | 1429.5 |
| | % Dev. | 55.9 | 124.2 | 141.5 | 83.0 | 118.7 | 1211.1 | 124.9 |

**Table: 9.** Change in seasonal runoff (mm) under option II of different watersheds located in different agro ecological regions of India for A2a scenario (PRECIS, IITM, Pune) during 1961-1990 and 2071- 2100

| Season | | Watersheds | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Almas | Antisar | Belura | Jonainala | Ooty | Pogalur | Umiam |
| Winter Monsoon | 1961-90 | 1.0 | 0.0 | 0.3 | 0.2 | 0.0 | 0.00 | 3.0 |
| | 2071-2100 | 2.0 | 0.0 | 0.18 | 3.7 | 0.8 | 0.00 | 11.0 |
| | % Dev. | 100.0 | 0.0 | -40.0 | 1750.0 | 80.0 | 0.0 | 266.7 |
| Pre-Monsoon | 1961-90 | 1.0 | 1.8 | 1.5 | 34.3 | 4.7 | 0.00 | 496.8 |
| | 2071-2100 | 3.0 | 3.1 | 8.00 | 56.2 | 11.1 | 0.50 | 1326.6 |
| | % Dev. | 200.0 | 72.2 | 433.3 | 63.8 | 136.2 | 50.0 | 167.0 |
| Monsoon | 1961-90 | 79.6 | 54.0 | 213.6 | 162.4 | 13.2 | 0.22 | 95.0 |
| | 2071-2100 | 192.1 | 181.0 | 578.61 | 343.8 | 38.4 | 0.17 | 321.6 |
| | % Dev. | 141.3 | 235.2 | 170.9 | 111.7 | 190.9 | -22.7 | 238.5 |
| Post-Monsoon | 1961-90 | 15.0 | 2.1 | 6.9 | 17.5 | 1.9 | 0.72 | 41.0 |
| | 2071-2100 | 27.0 | 5.1 | 39.05 | 47.8 | 30.5 | 8.84 | 61.7 |
| | % Dev. | 80.0 | 142.9 | 465.9 | 173.1 | 1505.3 | 1127.8 | 50.5 |
| Annual | 1961-90 | 96.6 | 57.9 | 222.3 | 214.4 | 19.8 | 0.94 | 635.8 |
| | 2071-2100 | 224.1 | 189.2 | 625.84 | 451.5 | 80.9 | 9.51 | 1720.9 |
| | % Dev. | 132.0 | 226.8 | 181.5 | 110.6 | 308.6 | 911.7 | 170.7 |

**Table: 10.** Change in seasonal runoff (mm) under option III of different watersheds located in different agro ecological regions of India for A2a scenario (PRECIS, IITM, Pune) during 1961-1990 and 2071- 2100

| Season | | Watersheds | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Almas | Antisar | Belura | Jonainala | Ooty | Pogalur | Umiam |
| Winter Monsoon | 1961-90 | 1.0 | 0.0 | 0.3 | 0.2 | 0.0 | 0.00 | 3.0 |
| | 2071-2100 | 1.0 | 0.0 | 0.11 | 2.8 | 0.1 | 0.00 | 6.0 |
| | % Dev. | 0.0 | 0.0 | -63.3 | 1300.0 | 10.0 | 0.0 | 100.0 |
| Pre-Monsoon | 1961-90 | 1.0 | 1.8 | 1.5 | 34.3 | 4.7 | 0.00 | 496.8 |
| | 2071-2100 | 2.0 | 1.8 | 6.69 | 50.1 | 4.8 | 0.40 | 992.0 |
| | % Dev. | 100.0 | 0.0 | 346.0 | 46.1 | 2.1 | 40.0 | 99.7 |
| Monsoon | 1961-90 | 79.6 | 54.0 | 213.6 | 162.4 | 13.2 | 0.22 | 95.0 |
| | 2071-2100 | 129.1 | 120.4 | 522.7 | 299.8 | 14.9 | 0.10 | 204.1 |
| | % Dev. | 62.2 | 123.0 | 144.6 | 84.6 | 12.9 | -54.5 | 114.8 |
| Post-Monsoon | 1961-90 | 15.0 | 2.1 | 6.9 | 17.5 | 1.9 | 0.72 | 41.0 |
| | 2071-2100 | 19.0 | 3.7 | 34.22 | 38.7 | 18.7 | 6.2 | 33.8 |
| | % Dev. | 26.7 | 76.2 | 395.9 | 121.1 | 884.2 | 761.1 | -17.6 |
| Annual | 1961-90 | 96.6 | 57.9 | 222.3 | 214.4 | 19.8 | 0.94 | 635.8 |
| | 2071-2100 | 151.1 | 125.9 | 563.6 | 391.3 | 38.5 | 6.7 | 1235.9 |
| | % Dev. | 56.4 | 117.4 | 153.5 | 82.5 | 94.4 | 612.8 | 94.4 |

**Table: 11. Annual runoff (mm) from various watersheds under various options for different durations**

| Watersheds | Base period (1961-1990) | Option I | | Option II | | Option III | |
|---|---|---|---|---|---|---|---|
| | | 2071-2100 | % Dev. | 2071-2100 | % Dev. | 2071-2100 | % Dev. |
| **1. Jonainala** | 214.4 | 392.3 | 83.0 | 451.5 | 110.6 | 391.3 | 82.5 |
| **2 .Pogalur** | 0.9 | 11.8 | 1211.1 | 9.5 | 911.7 | 6.7 | 612.8 |
| **3. Belura** | 222.3 | 536.9 | 141.5 | 625.8 | 181.5 | 563.6 | 153.5 |
| **4. KG-4** | 19.8 | 43.3 | 118.7 | 80.9 | 308.6 | 38.5 | 94.4 |
| **5. Almas** | 96.6 | 150.6 | 55.9 | 224.1 | 132.0 | 151.1 | 56.4 |
| **6. Umiam** | 635.6 | 1429.5 | 124.9 | 1720.9 | 170.7 | 1236.1 | 94.5 |
| **7. Antisar** | 57.8 | 129.6 | 124.2 | 189.2 | 226.8 | 125.9 | 117.4 |

**Table: 12.** Frequency of runoff (mm) exceeding in 30 years duration in different watersheds.

| Duration and percent deviation | Frequency of runoff(mm) exceeding in 30 years | | | | Total |
|---|---|---|---|---|---|
| | <50 | 50-150 | 150-300 | >300 | |
| **1. Joninala** | | | | | |
| 1961-1990 | 2 | 9 | 11 | 8 | 30 |
| 2071-2100 | 0 | 4 | 10 | 16 | 30 |
| Deviation (%) | -100 | -55.6 | -9.1 | 100.0 | - |
| **2. Pogalure** | | | | | |
| 1961-1990 | 30 | 0 | 0 | 0 | 30 |
| 2071-2100 | 27 | 3 | 0 | 0 | 30 |
| Deviation (%) | -10 | 300.0 | 0 | 0 | - |
| **3. Udhagamandalam** | | | | | |
| 1961-1990 | 30 | 0 | 0 | 0 | 30 |
| 2071-2100 | 18 | 12 | 0 | 0 | 30 |
| Deviation (%) | -40 | 1200.0 | 0.0 | 0 | - |
| **4. Almas** | | | | | |
| 1961-1990 | 9 | 21 | 0 | 0 | 30 |
| 2071-2100 | 3 | 27 | 0 | 0 | 30 |
| Deviation (%) | -66.6 | 28.5 | 0 | 0 | - |
| **5. Umiam** | | | | | |
| 1961-1990 | 0 | 2 | 5 | 23 | 30 |
| 2071-2100 | 0 | 0 | 1 | 29 | 30 |
| Deviation (%) | 0 | -100 | -80 | 26.1 | - |
| **6. Belura** | | | | | |
| 1961-1990 | 0 | 11 | 10 | 9 | 30 |
| 2071-2100 | 0 | 3 | 4 | 23 | 30 |
| Deviation (%) | 0 | -72.7 | -60 | 155.5 | - |
| **7. Antisar** | | | | | |
| 1961-1990 | 13 | 17 | 0 | 0 | 30 |
| 2071-2100 | 4 | 18 | 6 | 2 | 30 |
| Deviation (%) | -69.2 | 5.8 | 600 | 200 | - |

**Table: 13.** Rainfall Erosivity factor 'R '( m t cm ha-1 hr-1 year-1/100) for different watersheds representing different agro-ecological regions of India (Computed by empirical model of Ram Babu et al, 2004) , for GCM data of HADCM3 for different period

| S. No. | Watersheds | 1961-1990 | 2011- 2040 | 2041-2070 | 2071-2100 | Deviation between 1961-90 and 2071-2100 |
|---|---|---|---|---|---|---|
| 1. | Almas | 413.6 | 437.5 | 485.0 | 558.8 | 15.9 |
| 2. | Antisar | 497.8 | 512.9 | 510.6 | 531.5 | 15.5 |
| 3. | Belura | 524.4 | 503.0 | 515.7 | 552.8 | 36.5 |
| 4. | Jonainala | 598.3 | 614.5 | 637.3 | 694.5 | 20.5 |
| 5. | Ooty | 853.1 | 828.4 | 794.9 | 930.3 | 3.0 |
| 6. | Pogalur | 841.7 | 848.7 | 793.8 | 800.0 | 8.5 |
| 7. | Umiam | 801.6 | 785.5 | 888.9 | 964.2 | 43.8 |

**Table: 14. Soil loss (t ha$^{-1}$) of selected watersheds**

| S.No. | Watersheds | Soil loss (t ha$^{-1}$) | | |
|---|---|---|---|---|
| | | 1961-1990 | 2071-2100 | Deviation (%) |
| 1 | **Almas** | 1.85 | 2.6 | 40.54 |
| 2 | **Udhagamandalam** | 8.63 | 8.95 | 3.71 |
| 3 | **Umiam** | 14.54 | 24.82 | 70.70 |
| 4 | **Pogalure** | 0.007 | 0.06 | 757.14 |
| 5 | **Belura** | 0.29 | 1.07 | 268.97 |
| 6 | **Joninala** | 2.15 | 2.78 | 29.30 |
| 7 | **Antisar** | 0.031 | 0.049 | 60.00 |

**Table: 15.** Relationship between agriculture /market value of land and various rainfalls of different districts of Uttarakhand

| Sl No. | Combinations between agriculture /market value of land and rainfall | Linear Equation | $R^2$ value |
|---|---|---|---|
| 1 | Market value of land Vs average annual rainfall | y = 226.34 x | 0.7312 |
| 2 | Market value of land Vs average kharif rainfall | y = 307.65 x | 0.7196 |
| 3 | Market value of land Vs average July rainfall | y = 811.11 x | 0.8344 |
| 4 | Agricultural value of land Vs average annual rainfall | y = 13.58 x | 0.7312 |
| 5 | Agricultural value of land Vs average kharif rainfall | y = 18.459 x | 0.7196 |
| 6 | Agricultural value of land Vs average July rainfall | y = 48.666 x | 0.8344 |

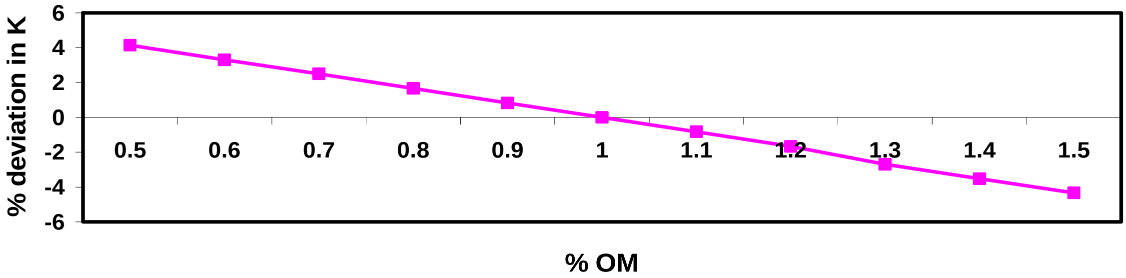



**Fig:-1. Percent deviation in 'K' with respect to % organic matter**

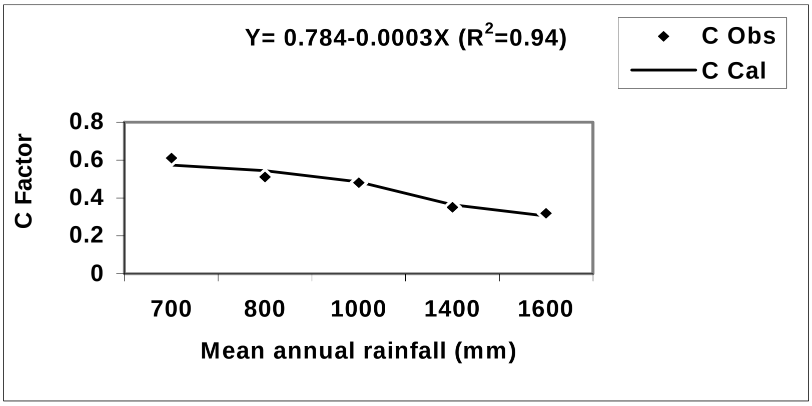



**Fig: 2.** Observed and calculated values of C factor in case of open tilled crops in different amount of mean annual rainfall

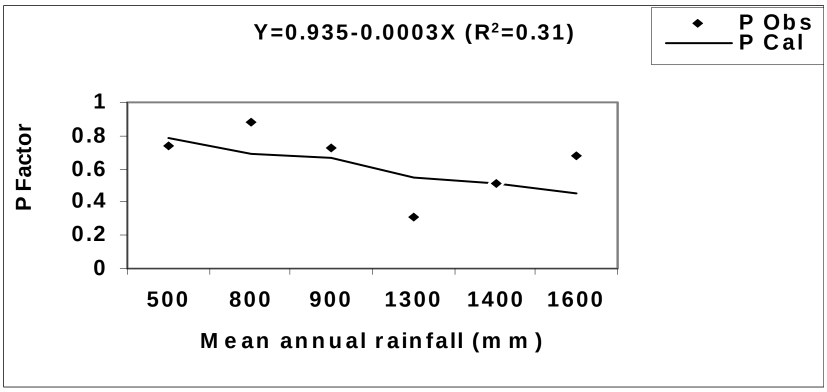



**Fig: 3.** Observed and calculated values of P factor in case of contour cultivation in different amount mean annual rainfall.

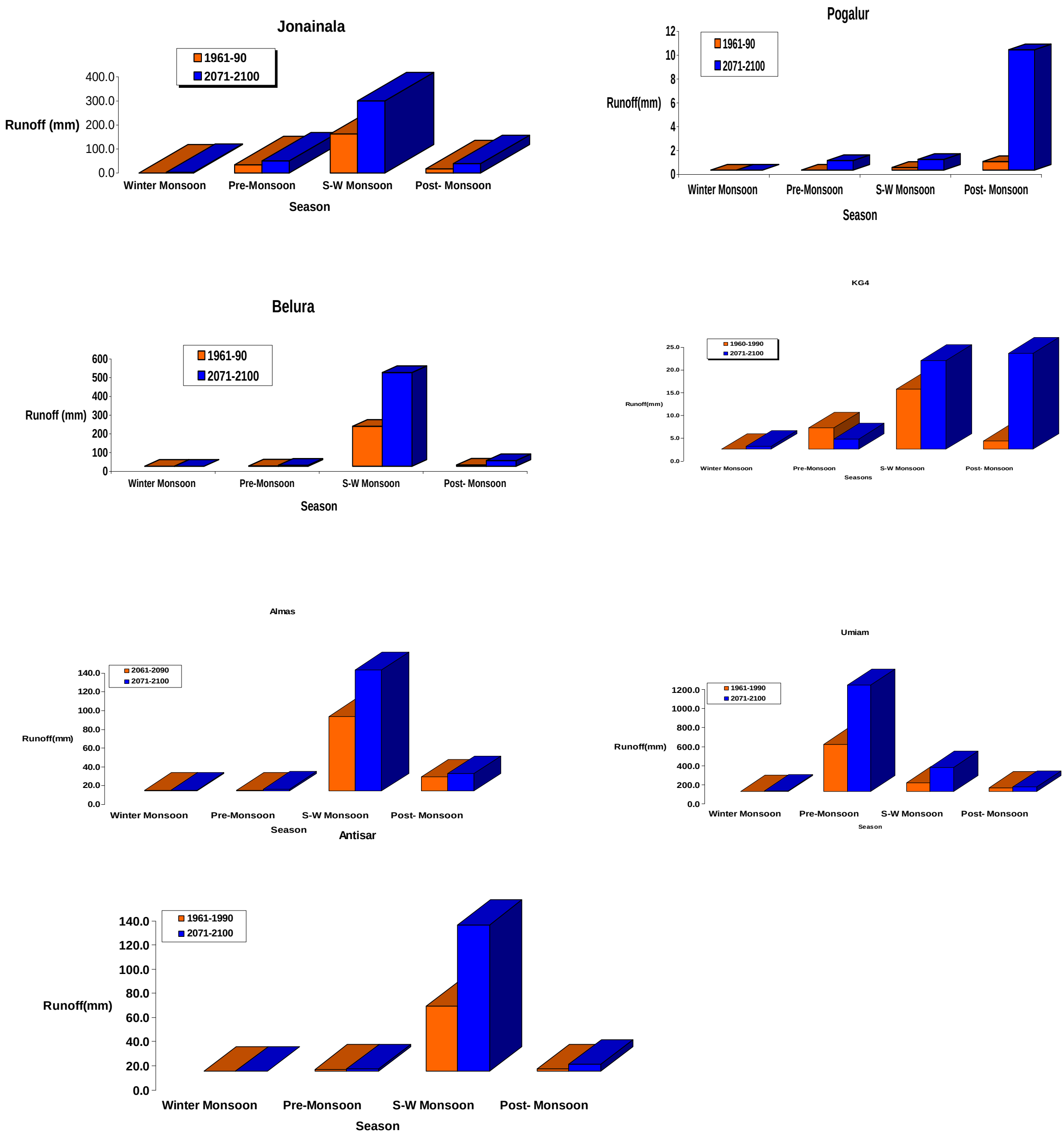



**Figure: 4.** Seasonal runoff of different watershed for 1961-1990 and 2071- 2100 for option no. I

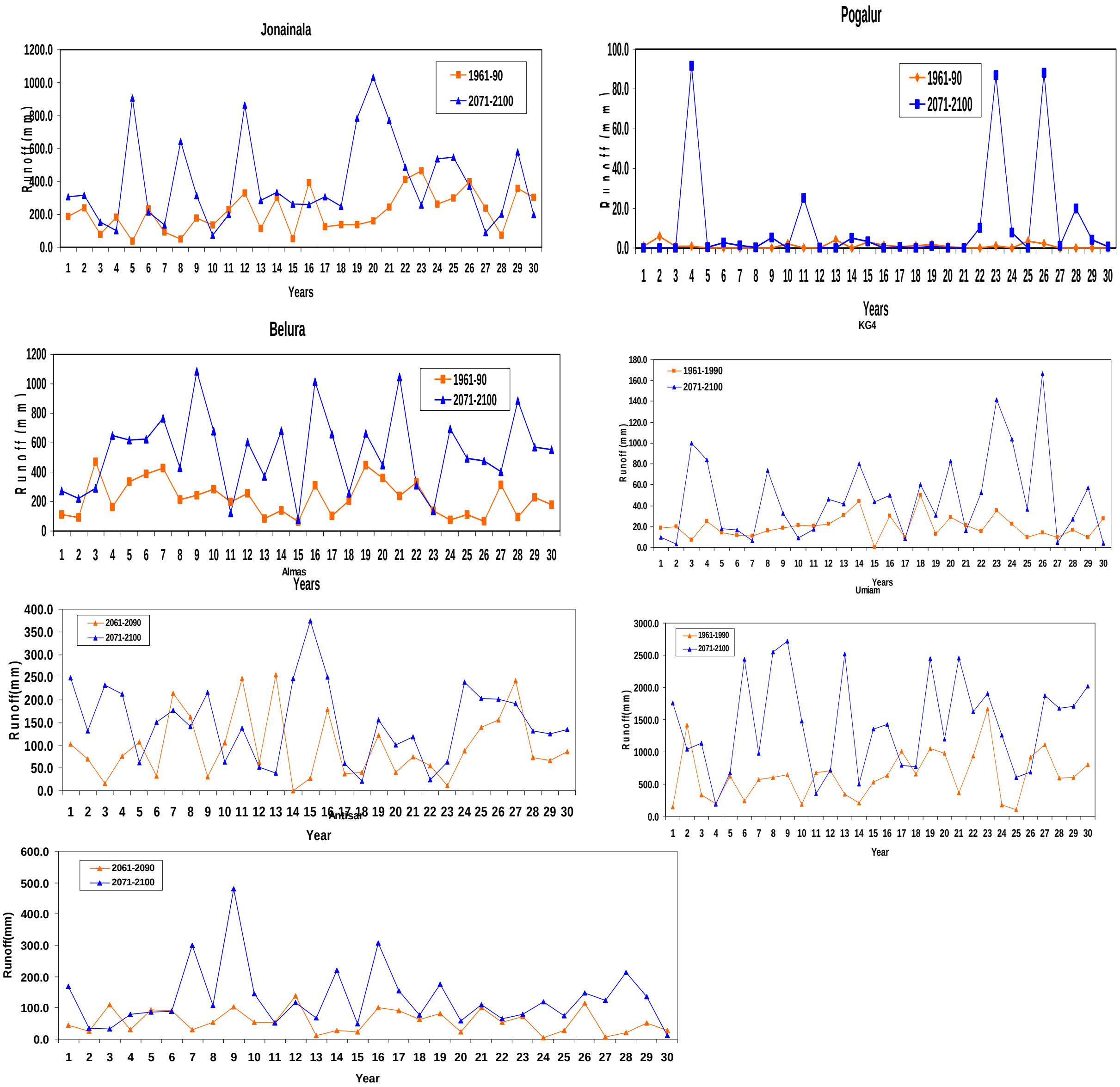



**Figure: 5.** Annual runoff of different watershed for 1961-1990 and 2071- 2100 for option no. I

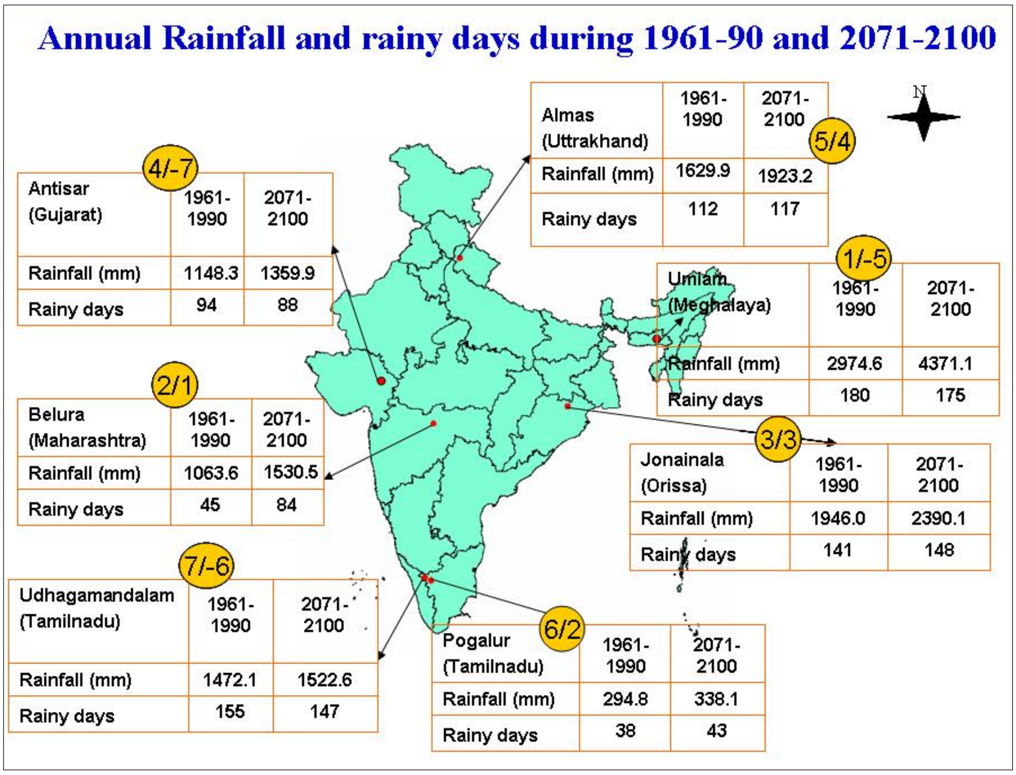



**Figure: 6.** Rainfall and rainy days during 1961-90 and 2071-2100 from different agro-ecological regions of the country

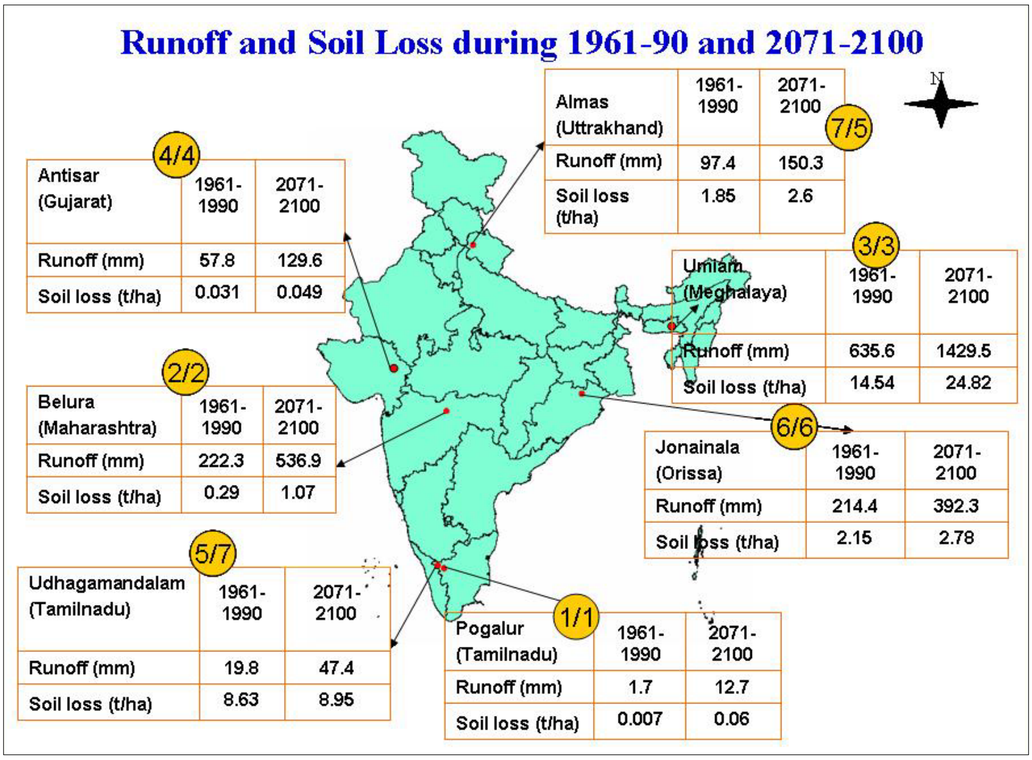



**Figure: 7.** Runoff and Soil Loss during 1961-90 and 2071-2100 from different agro-ecological regions of the country

# ICAR Research Complex for Eastern Region, Patna

To investigate the impact of climate change on the hydrology and spatial and temporal variability in water availability, Brahmani basin (catchment area 39313 sq. km.) which is spread over three states of Orissa, Jharkhand and Chhatisgarh, has been selected under ICAR Network Project on Climate Change "Impact, Adaptation, Vulnerability of Indian Agriculture to Climate Change." A detailed literature survey has been done with respect to modeling impact of climate change on water resources (modeling methodology, different models used for impact studies, development of modeling framework for impact studies and preparation of adaptation strategies), generation of climate change scenarios, and vulnerability assessment. Based on this, the status paper on impact, adaptation and vulnerability of water resources and irrigation to climatic variability and climate change has been prepared. Further, review on trend analysis methods used for climate change studies and trends in change in climatic variables over India have been done. For above study, time series data of different hydrometeorological variable has been collected and trend has been studied using different statistical tests. The different thematic maps, land use, soil type elevation maps (with 30 m resolution) has been developed and analyzed using TNTmips and PCI Geomatica software for delineation of the basin into sub-watersheds and HRUs. The distributed hydrological model has been applied to simulate the streamflow under different climate change scenarios. Further, impact of climate change on evapotranspiration/irrigation water demand has been simulated using SWAP model under different climate change scenarios. Effects of climatic change on crop production and input use under different scenarios of water availability has also been studied. The details of work done during the report period are summarized below:

1. **Trend Analysis of Hydrometeorological Variables:** Before studying the impact of climate change on water resources under different climate change scenarios, an attempt has been made to study the trend of different climatological (rainfall, mean temperature, and mean relative humidity) and hydrological (streamflow) variables using historical time series data of different locations spread over the basin. For this purpose rainfall data of eleven locations, temperature and relative humidity of five locations and streamflow data of four gauging stations have been collected and analyzed.

For analyzing the trend Mann-Kendall test, Spearman's Rho test, linear regression test (t-test) and Sen's slope test have been employed. Trend homogeneity test has also been conducted using the procedure based on partitioning the sum squares (van Belle and Hughes, 1984[1]). The results of trend analysis of different hydrometeorological variables are summarized below:

- In general there is decreasing trend (though non-significant at 95%) in mean monthly rainfall throughout the basin. In the month of February there is decrease in rainfall at all the stations but the decrease is significant only at Dhenkanal in Orissa. There is significant (significance level 95%) increase in mean monthly rainfall in November at Jenapur, in June at Gomlai, Anandpur and Swampatna; and in July at Bolani. The central part of the region particularly Panposh and Gomlai (except Bolani where it is decreasing) showed increasing trend and all the stations lying in south-east part of the basin showed decreasing trend.

- There is decreasing trend in annual and seasonal rainfall (rainy, summer, winter) in Bolani and Swampatna and increasing trend at Panposh. During rainy season there is significant increase in rainfall at Gomlai, whereas there is significant decrease at Jashpurnagar. Jashpurnagar also recorded significant decrease in annual rainfall amount
- Most of the stations in the basin showed increasing trend (though not significant at 95 % level) in mean monthly temperature. In the month of July and August, all the five stations recorded increasing trend in mean monthly temperature. Increasing trend was observed in most of the months in Angul (except March) and Jashpurnagar (except April). The increase in mean monthly temperature was significant (95 % level) during July-October at Angul and July-August at Jashpurnagar.
- Trend analysis of mean monthly relative humidity (RH) showed decreasing trend in most of the stations in the basin. Keonjhargarh and Paradip recorded decreasing trend in all the months (except January and February in the case of Paradip).
- In general, the basin exhibits upward trend in temperature and downward trend in RH. Further, it is to be noted that as one moves from upstream (Jashpurnagar) of the basin towards the downstream (Paradip), there is decreasing trend in RH.
- Application of four different trend detection tests to monthly, annual mean, maximum, minimum and low flow series in Brahmani basin showed almost similar results (Fig. 1). Significant increase is observed in mean monthly streamflow during October, November and December months in all the four stations. There is also a significant increase in the annual minimum and low flow series.
- Trend for homogeneity test indicated consistency across stations but heterogeneity among different months. Overall there is a significant increase in the month of October, November, December, March and April with maximum increase in the month of November followed by October, December, March and April.

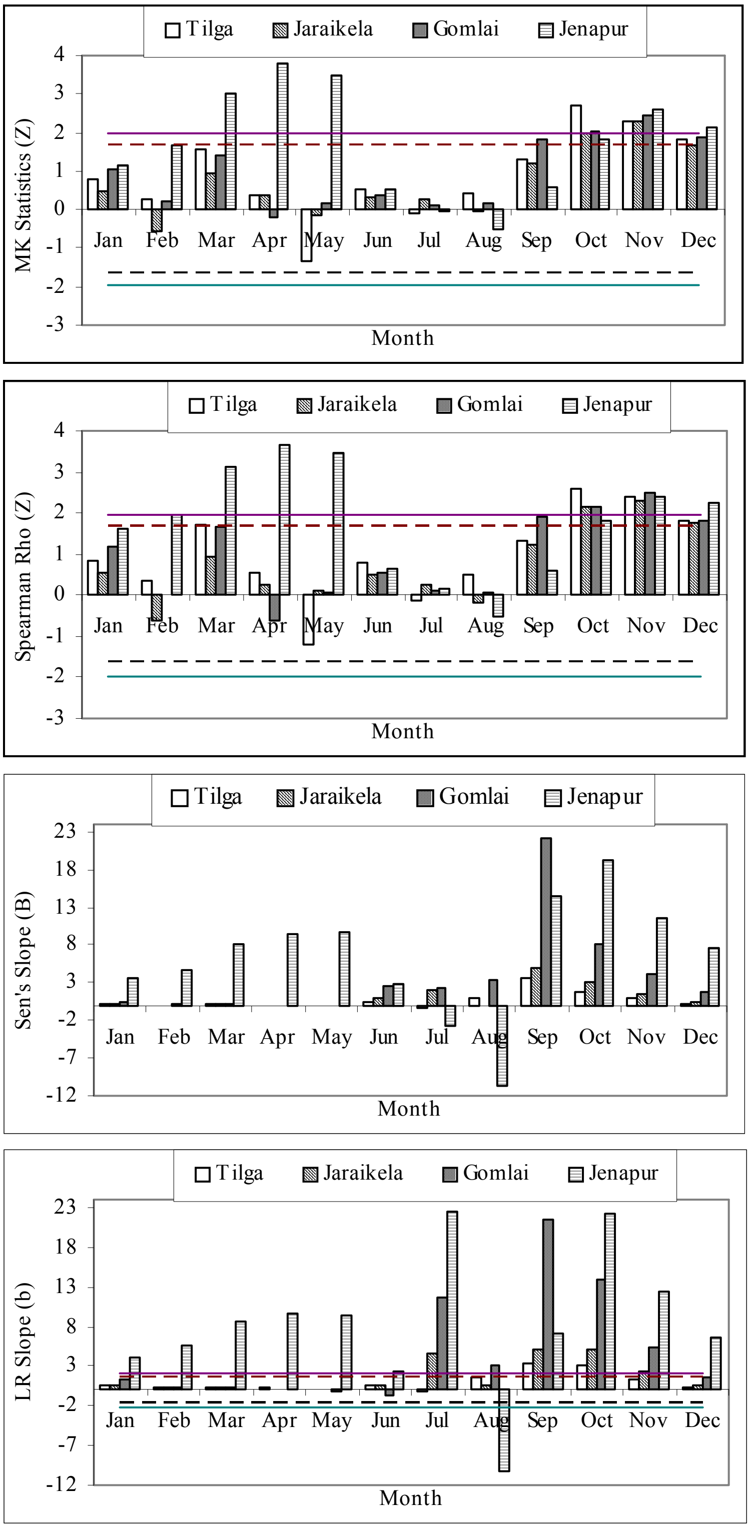



**Fig. 1**. Trend statistics of different trend detection method.

## 2. Delineation of Basin into different HRUs

Geographical extent of the basin was delineated using toposheets (1: 250000 scale) and digitized in a GIS environment. Different thematic layers like soil types, land use, and elevation have been developed. Generations of different thematic layers are described below:

**Soil & Landuse:** Soil and land use maps collected from NBSS & LUP have been geo-referenced and digitized. Raster and vector layers of land use have been developed from the scanned maps in digital format and different soil groups have been merged to form six groups on the basis of textural classes. Six broad soil types, namely, silt loam, loam, sandy loam, clay, loamy sand, and clay soil textures have been identified. Similarly, four different landuse types, namely, cultivated area, forest area, water bodies and settlement have been identified in the basin.

**Digital Elevation Model:** Contours at 60 m intervals were digitized after geo-referencing the toposheets for generation of the Digital Elevation Models. The DEM was generated in two stages. At the first stage it was generated with 100m horizontal resolution and 1 m vertical resolution and was further refined with 30m horizontal resolution and 1 m vertical resolution to get better estimates of elevation and slope parameter of different HRUs. The interpolated elevation layer was also used to divide the basin into four sub-basins.

**Hydrological Response Units (HRUs):** The DEM along with soil and land use layers were used for generation of spatially distributed hydrological response units which were used as input to PRMS model for estimating runoff in the basin. For delineation of watershed into different HRUs elevation, landuse and soil layers were categorized into 3, 2, and 6 classes respectively and nineteen different classes of Hydrological Response Units. The entire basin was delineated into and 66 spatially distributed HRUs (Fig. 2).

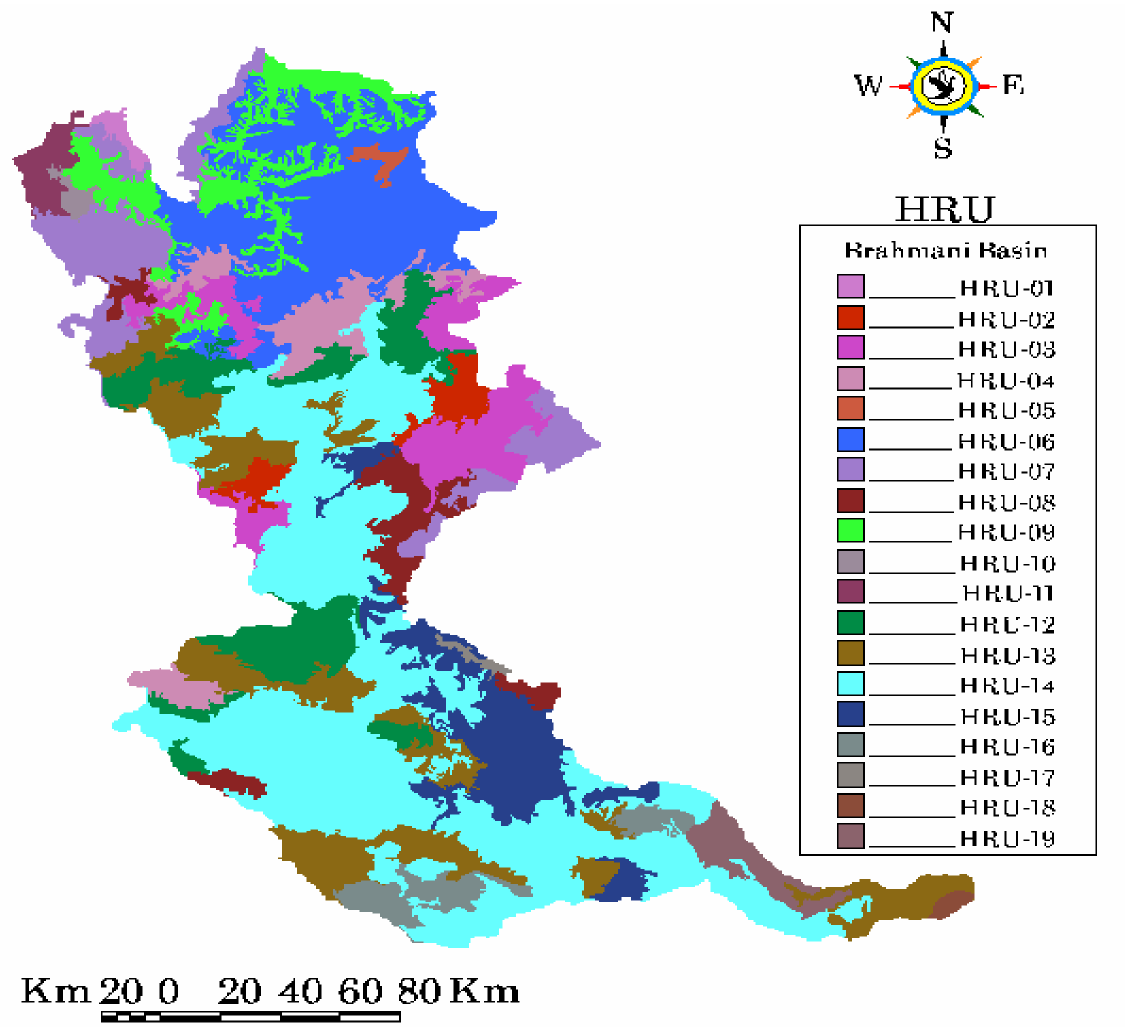



**Fig. 2.** Different HRUs of the Brahmani basin

### (C) Hydrological Modeling to Study the Impact of Climate Change on Water Resources

The impact of climate change on the hydrology and water availability in the Brahmani basin has been studied using USGS (United States Geological Survey) MMS/PRMS (Modular Modeling Systems/Precipitation-Runoff Modeling Systems) model. The Precipitation Runoff Modeling System (PRMS) is a distributed parameter, physical process based watershed model. Distributed parameter capabilities of the model are provided by partitioning the watershed into units, using characteristics such as slope, elevation, aspect, vegetation type, soil type, and precipitation distribution. Each unit, termed as hydrologic response unit (HRU) is assumed to be homogenous with respect to its hydrological response and to the above listed characteristics. Different characteristics (such as area, mean and median elevation, slope, land use and soil type etc) of each HRUs were extracted and used as input to the PRMS model.

**Model Calibration**: The MMS-PRMS model was calibrated by matching the observed and simulated streamflow on annual, monthly and daily basis at four spatially distributed gauging stations (namely, Tilga, Jaraikela, Gomlai and Jenapur). The calibration of the model for four different gauging stations showed a good agreement between observed and simulated streamflow. The coefficient of determination and modeling efficiency (Nash-Sutcliffe coefficient) was found to be 0.96 and 0.90, respectively during calibarion phase (Fig. 3), and 0.99 and 0.98 respectively during validation phase (Fig. 4) for Jenapur. For other three locations coefficient of determination and modeling efficiency varied from 0.91 to 0.98 and 0.89 to 0.96, respectively during calibration phase; and 0.84 to 0.97 and 0.80 to 0.84, respectively during validation phase (Table 1). Sensitivity analysis of the model under different hypothetical scenarios indicated 4.8% decrease in annual streamflow with 4 °C increase in temperature and no change in rainfall; and 22.5% decrease in annual streamflow with 10% decrease in precipitation and no change in temperature (Fig. 5).

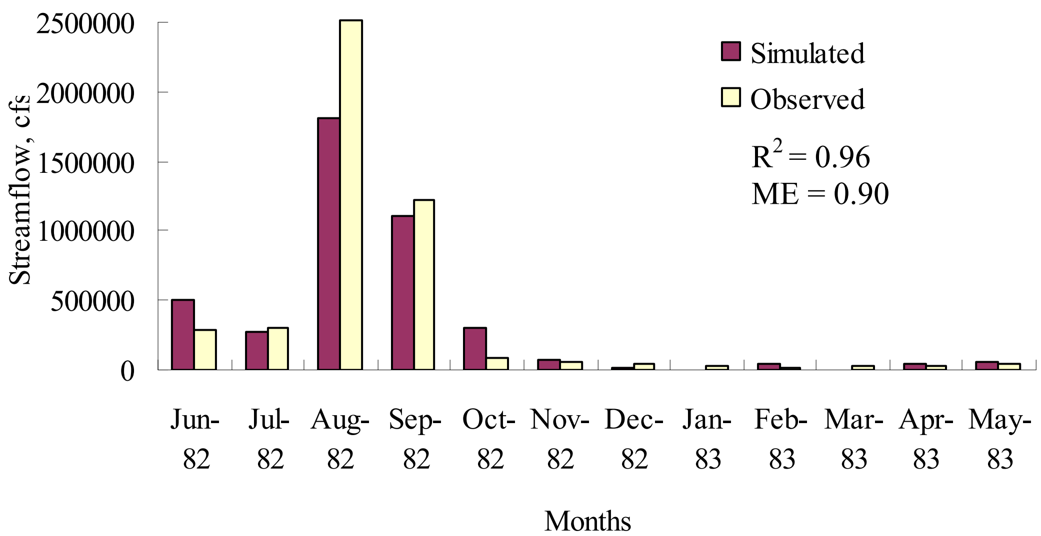



**Fig 3**. Monthly observed and simulated streamflow at Jenapur during calibration period

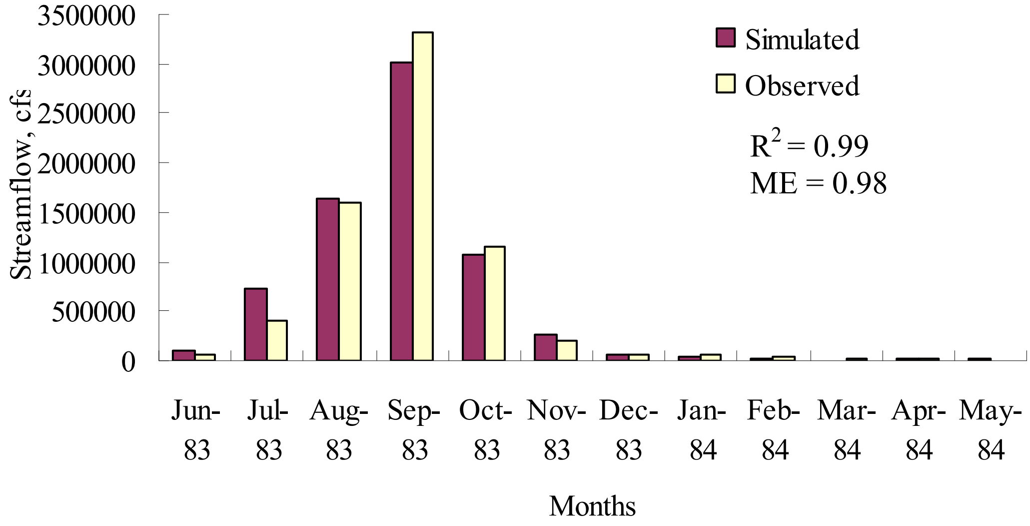



**Fig. 4**. Monthly observed and simulated streamflow at Jenapur during validation period

**Table 1**. Summary of error statistics for calibration and validation period at different gauging stations

| Station | Calibration Period (1983-84) | | Validation Period (1984-85) | |
|---|---|---|---|---|
| | $R^2$ | ME | $R^2$ | ME |
| Jaraikela | 0.91 | 0.90 | 0.84 | 0.84 |
| Tilga | 0.94 | 0.89 | 0.97 | 0.80 |
| Gomlai | 0.98 | 0.96 | 0.96 | 0.83 |

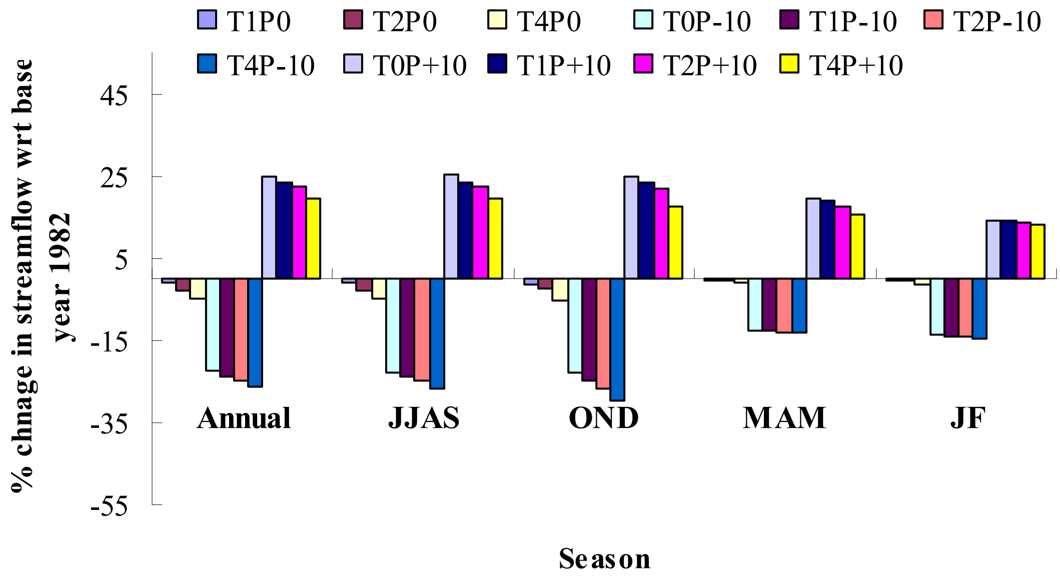



**Fig. 5**. Streamflow sensitivity to different hypothetical climate change scenarios

For simulating streamflow during 2020 (2010-2039) and 2050 (2040-2069), rainfall and temperature data were generated by LARS-WG (Long Ashton Research Station Weather Generator) using the base year (1961-91) and future scenarios (2071-2090) data of PRECIS RCM adopting the procedure suggested by Semenov and Barrow (2002)[2]. Simulation results using PRECIS RCM scenario for the year 2020 and 2050 showed 25 and 31% increase in annual streamflow at Jenapur, respectively (Fig. 6), over the base year (1980) with maximum increase recorded during the month of December (Fig. 7). During the months of February to Jun, there is decrease in mean monthly streamflow in 2020 as well as 2050. Similar results were also obtained using HadCM3 generated scenarios, predicting an increase in annual streamflow by 43, 30 and 64 percent during 2020, 2050, and 2080 respectively.

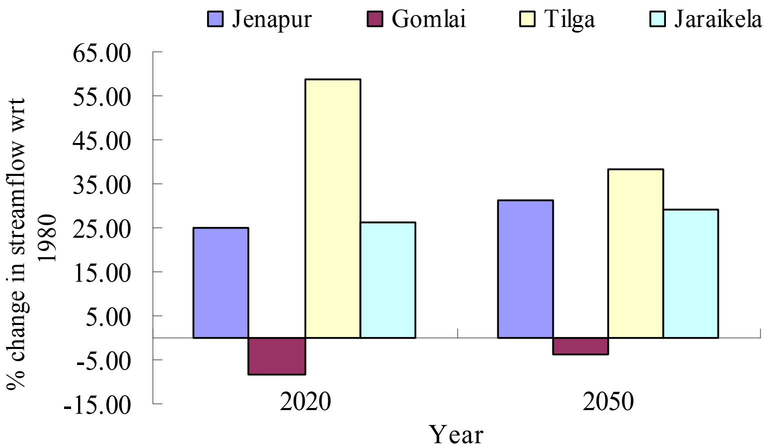



**Fig. 6**. Change in annual streamflow at different locations during 2020 and 2050

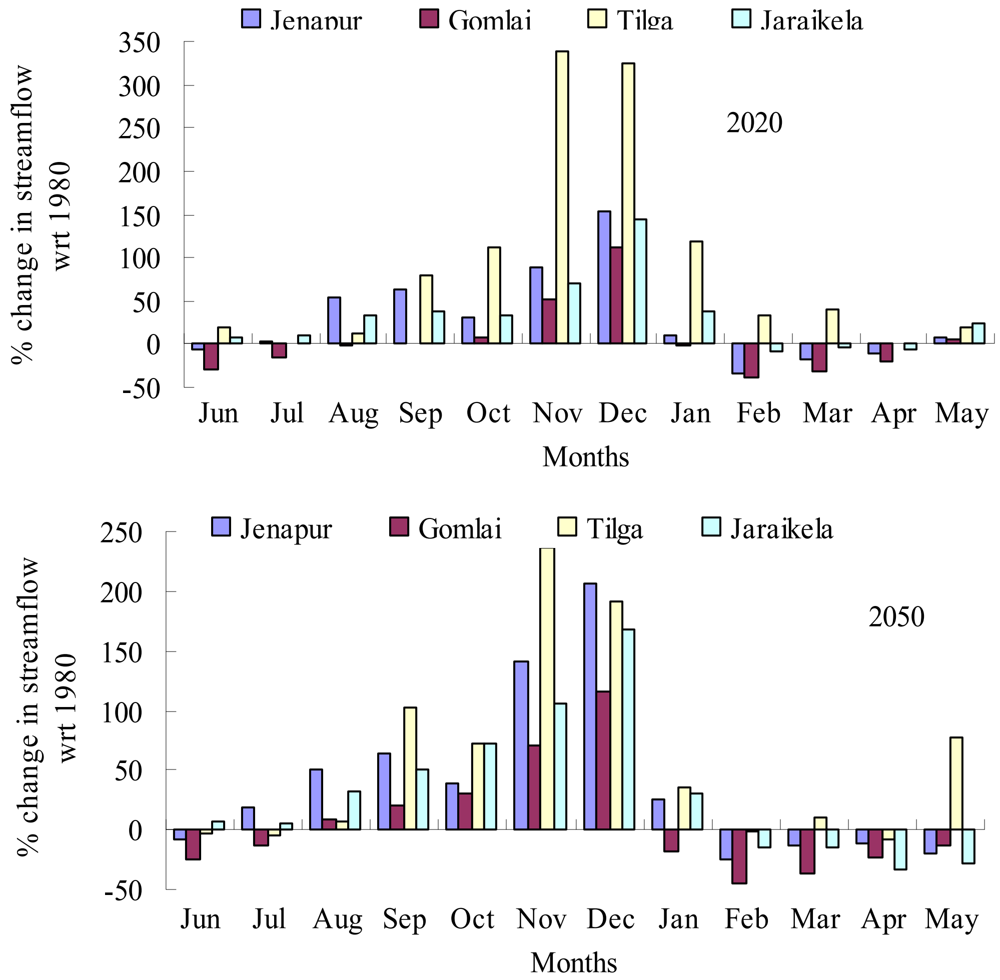



**Fig. 7**. Change in monthly streamflow at different locations during 2020 and 2050.

Similar to Jenapur, other stations too showed decrease in mean monthly streamflow during February to June with maximum decrease at Gomlai during these months (Fig 7). Though there is increase annual streamflow at Tilga, Jaraikela and Jenapur but there is decrease in annual streamflow at Gomlai in 2020 and 2050 (Fig. 6). The study clearly indicates temporal as well as spatial variability in the availability of water resources in the basin under the influence of future climate change and need for development of different adaptation strategies for different locations.

**(D) Impact of Climate Change on ET**

In order to study the impact of climate change on actual and potential evapotranspiration at a relatively micro-scale during kharif and rabi season Derjang Irrigation Project site within Brahmani basin (Latitude 20° 50″ Longitude 85° 02″) located in District Angul, in Orissa was selected. The GCA and CCA of the Irrigation Project are 11,780 and 7,893 ha, respectively. Rice is predominant crop of the area, besides other crops like Groundnut, Pulses, Sugarcane, Sunflower, and Til are cultivated in few patches. Four scenarios in 'what if' mode selected are hypothetical scenarios of temperature changes alone by ± 1°C to ± 4°C from the base year (2000) data, temperature increase by 1°C to 3°C with rainfall decrease by 10 %, and temperature increase by 1°C to 3°C with rainfall increase by 10%. The study was carried out employing Soil-Water-Atmosphere-Plant (SWAP) interaction model with the available soil, water, crop, and climate data collected from the project site. Variation in actual ET due to increase or decrease in temperature in the range of 1°C to 4°C is presented in Fig. 8.

Results revealed that during rabi season AET was found to increase from 2.25% to 9.71% when temperature was increased by 1°C to 4°C whereas it was found to decrease from 2.43% to 8.85% when temperature was reduced by 1°C to 4°C. During kharif season AET was found to increase from 2.84 % to 11.04% when temperature was increased by 1°C to 4°C, whereas it was found to decrease from 2.39 % to 10.09%, when temperature was decreased by 1°C to 4°C.

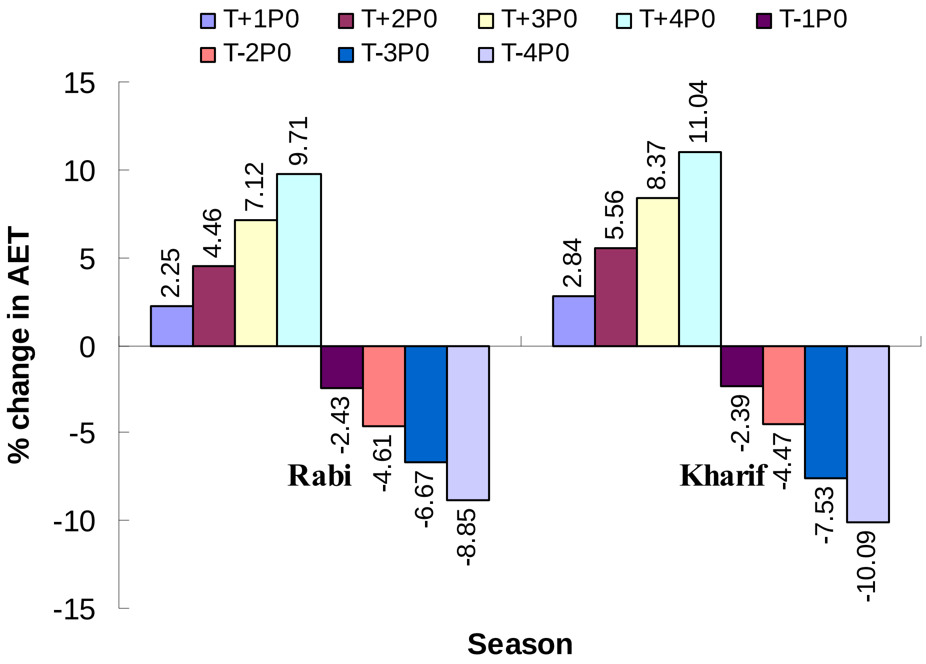



**Fig. 8:** Percent variation in AET due to change in temperature (°C).

Variation in actual ET under the scenario of increase in temperature by 1ºC to 3 ºC along with decrease or increase in rainfall by 10% is presented in Fig 9. Results revealed that during kharif season AET was found to increase from 5.37% to 13.85% when temperature was increased by 1ºC to 3 ºC with decrease in rainfall by 10%, whereas it was found to be increase from 3.77% to 11.94% when temperature and rainfall were increased by 1ºC to 3 ºC and 10%, respectively. During rabi season AET was observed to increase from 3.11% to 9.60% when temperature was increased from 1 ºC to 3 ºC and rainfall was decreased by 10%, whereas it was found to increase from 3.07% to 9.45% when temperature and rainfall were increased by 1 ºC to 3 ºC and 10 %, respectively. The results indicate that the scenario of increase in temperature and decrease in rainfall are more vulnerable and will have adverse impact on irrigation water demand.

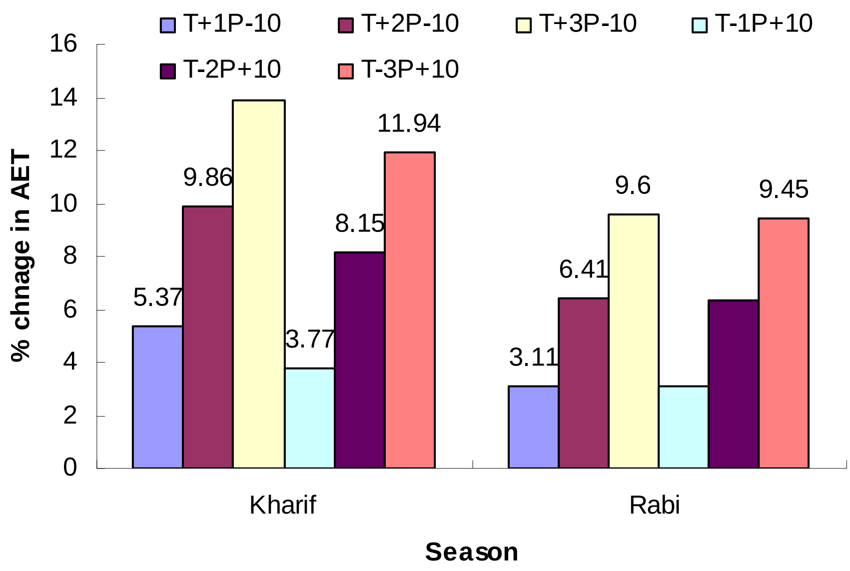



**Fig. 9.** Percent variation in AET due to change temperature (°C) and rainfall (%)

### (E) Effect of Climatic Change on Crop Production and Input Use in Derjang Command Area

Data on crops grown, inputs used, yield and prices of different farm products produced in the command were collected from farmers by conducting focused group discussions and personal interviews. Crop preferences of the farmers in the situations of water deficit as well as excess were also recorded. Future crop scenarios were worked out based on the preferences of the farmers and expected water scenario in order to understand adaptability. Quantity and value of crop production and input requirements were worked out and compared based on the collected data. Rice is grown in 85.11 percent area of the gross command. Pulses are grown in 575 ha area followed by vegetables (378 ha). In case of increased water availability scenarios, farmers preference was to increase rabi rice area and to shift from rice area to pulses in case of decreased water availability.

Input requirement and yields of different crops in the command area were worked out based on different scenarios. At present the cost of the inputs used was worked out to be Rs. 1424.41 lakh and the value of the production was Rs. 2052.29 lakh. Value of the production was found to increase to Rs. 2093.62 lakh for scenario of 10% increase in rainfall. Similarly value of inputs also increased to Rs. 1461.52 lakh. However, no decrease in the value of production was found for the scenario of 10% decrease in rainfall. This was mainly due to the shift in the crop area from rice to pulses as it needs less input compared to rice. In this hypothetical case, value of inputs used decreased to Rs. 1404.08 lakhs and value of out put increased by Rs. 3.47 lakhs. This hypothetical study indicates that by changing crops alone in the event of climate change, economic vulnerability could be reduced. This suggests that option of various simple crop, land and water management strategies/interventions need to be looked into for adaptation to climate change.

## National Dairy Research Institute, KARNAL

### 1.0 Impact of climate change on milk production:

The potential direct effects of possible climate change and global warming on milk production of Indigenous, crossbred cattle and buffaloes were evaluated using widely known global circulation model UKMO to represent possible scenarios of future climate ((SAS region-23, Ruosteenoja *et al.*, 2003). A temperature rise of 1.0 or 1.2° C with minor change in precipitation during March – August for India (Region 23- HADCM3 A2/B2 scenario) will marginally affect milk production. A small change in THI due to rise in temperature is not likely to cause much effect on physiological functions as animals have enough capacity to adapt, but both milk production and reproductive functions of cattle and buffaloes will be adversely affected by projected temperature rise of 2-6° C over existing temperatures for time slice 2070-2099.

The negative impact of temperature rise on total milk production for India has been estimated about 1.6 million tones in 2020 and more than 15 million tones in 2050 (Fig.1). The partitioning of milk production impact indicated that high producing crossbred cows and buffaloes will be affected more, accounting 0.4 million and 0.89 million respective annual decline in 2020 (Fig.2a and b). Warming will also negatively impact the productivity of indigenous cows and productivity loss will be about 0.33 million tones milk in 2020(Fig.2c). The Northern India is likely to experience negative impact of climate change on milk production of both cattle and buffaloes due to rise in temperature during 2040-2069 and 2070-2099. The decline in milk production will be higher in crossbreds (0.63%) followed by buffalo (0.5%) and indigenous cattle (0.4%).

**Figure-1: Total Milk Production & Impact of Climate Change**

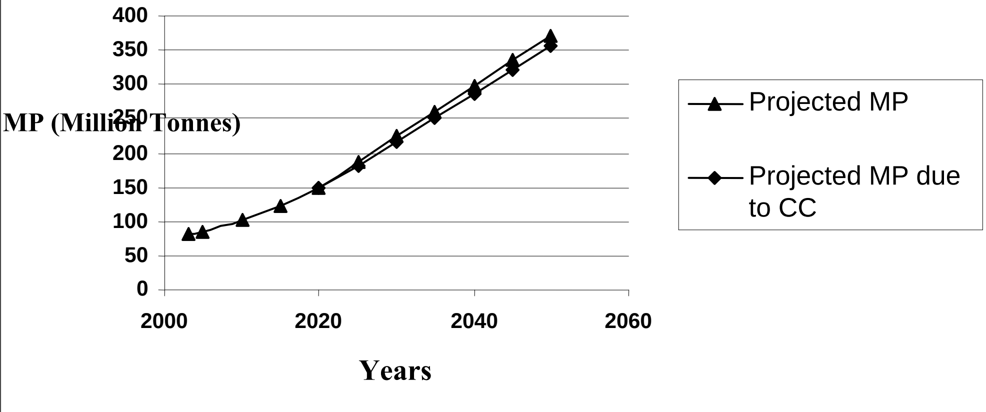


**Figure-2a: All India CB Milk Production & Impact of Climate Change**

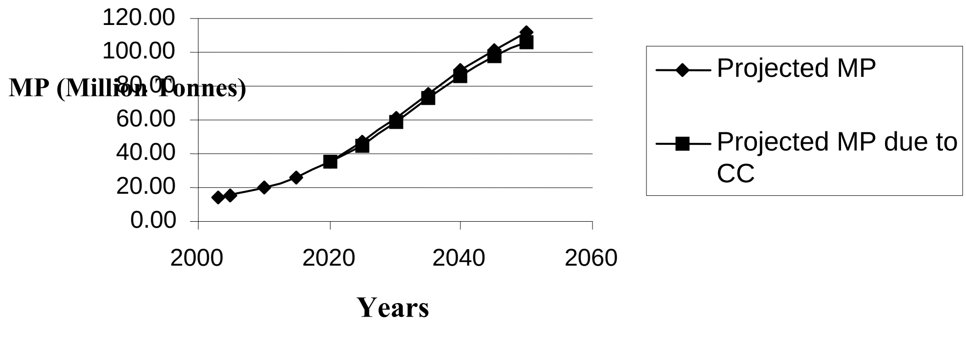



**Figure.2b: All India Indigenous Cattle Milk Production & Impact of Climate Change**

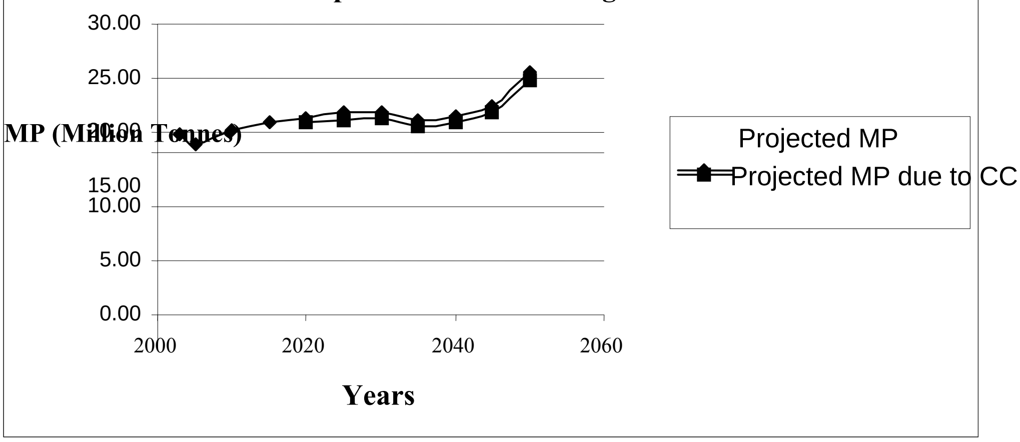
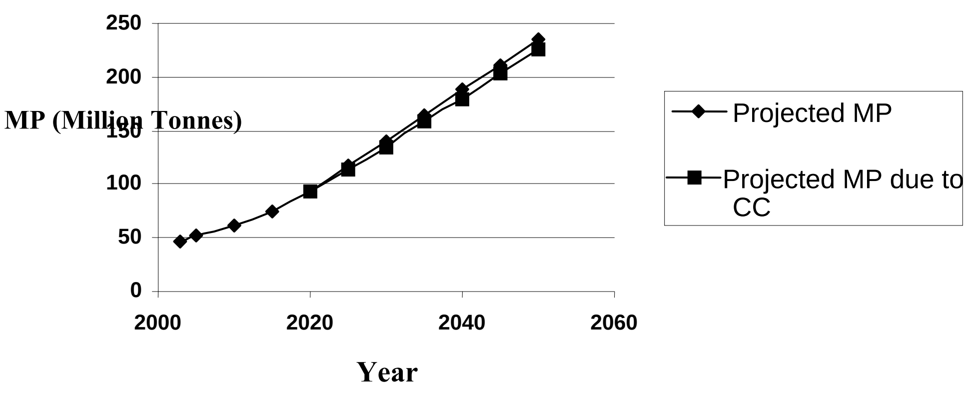



**Figure.2c: All India Bufflao Milk Production & Impact of Climate Change**



## 2.0 Evaluation of livestock for thermal / heat tolerance

Thermal tolerance of Zebu, Karan Fries crossbreds and buffaloes were evaluated after exposure to ambient temperature conditions on open sunny days from 8AM to 4 PM. Physiological reactions were recorded prior to exposure and after exposure and the data on Respiratory frequency, Heart rate and Rectal temperature change representing stress was used for calculation of heat tolerance coefficients and heat load. The results on Sahiwal, crossbreds were also compared with earlier Heat Adaptability studies carried out at this Institute during 1970- 1975 (Thomas et al, 1972). The results of present investigation and earlier study carried out indicated no perceptible changes in heat adaptability coefficients of Sahiwal and crossbreds maintained at the Institute during last thirty years. The adaptability results indicated that Sahiwal cattle are more heat tolerant followed by Tharparkar, Buffaloes and Crossbred cattle (KF) at Karnal.

Coefficient of Heat Tolerance = 100 - [10 (BT-101.0)], where BT is body temperature °F.
Gaalaas Heat tolerance test = 100-[14 (BT-101.0)], where BT is body temperature °F.
Dairy Search Index = 0.5RT/RT*+ 0..2RR/RR*+ 0.3HR/HR*, where RT is rectal temperature, RR is respiration rate/ min. and HR is heart rate/ min after exposure of animals and RT*, RR* and HR* are normal rectal temperature, respiration rate and heart rate, respectively.

## 3.0 Temperature humidity Index and thermal stress

The temperature humidity index (THI*) is a valuable tool to represent stress of hot weather climates. The index is based on dry bulb temperature and relative humidity. THI map of India has been developed based on more than 100 locations (Figure3). The results indicate that on an average the THI values in coastal regions exceed the comfortable conditions during most part of the year, which affect productivity. In other areas particularly northern to southern region the THI is generally higher than 73 from March to September, which is also uncomfortable to animals. In the northern areas, THI from March to September ranges between 70-75. In the hilly regions, the THI values are generally lower than 70, therefore animals remain in comfortable conditions during most part of the year. Livestock are comfortable at THI between 65 and 72, under mild stress from 72 to 78 and above 80 under severe stress. Analysis of THI map in relation to cattle breed locations indicated that high THI zones of India was predominantly dominated by indigenous or non -descript animals due to their better adaptive capacity and ability to cop up with feed scarcity/harsh environmental conditions. High thermal stress (THI > 78) requires greater efforts to dissipate heat. High producing livestock need to be cooled artificially by sprinklers particularly in hot dry conditions or if both high temperature and humidity prevail increased air movement is required to sustain milk production.

*THI= 0.72(Db° C +Wb° C) + 40.6, where db is dry bulb and Wb is wet bulb temperature, °C.

## 4.0 Thermal changes, THI and animal response functions

### 4.1. Temperature and heat alleviation functions

The sensitivity of livestock to increasing ambient temperature were tested by exposing Zebu, crossbred cattle and Murrah buffaloes to increasing hot ambient temperature (26-40°C) as observed during summer and low/ cool temperature (6-16°C) during winter. All experimental animals were monitored for their physiological responses and surface temperature at head, hump, rump, ear, fore and hind legs by an infrared thermometer. Animal sweating response was also measured on the rump surface using ventilated cup. Body heat storage was calculated from the weighted skin and rectal temperature of individual animal {Heat storage (KJ) = 3.47x body weight (Kg)*(0.8 ΔRT+0.2 ΔST)}. Physiological reactions and skin surface temperature were found to be very sensitive to increase in day temperature. The temperature and cardinal physiological reactions were lowest during early morning (between 4-6 am) and highest during afternoon/ evening (2-4pm). Interrelationship of Physiological functions with ambient temperature/ THI is presented in Table1. A significant positive correlation ($P<0.01$) was observed among physiological responses and ambient temperature. The sweating rate was more in Zebu (1178 gm/$m^2$/hr) than crossbreds (711gm/$m^2$/hr) or buffaloes (678gm/$m^2$/hr). Temperature humidity Index and heat storage were also positively correlated during summer. The study revealed that Zebu animals under hot dry/ hot humid conditions are less sensitive to changes in temperature as compared to low heat tolerant Karan Fries- Zebu crosses or Murrah buffaloes.

**Table.1. Physiological Functions in relation to Ambient Temperature**

| BREED | PARAMETER | $R^2$ | EQUATION |
|---|---|---|---|
| **BUFFALO*** | Amb.T-TotalE L | 0.8796 | y = 103.3x - 2581.9 |
| (38.3 to 39.7°C) | RT-RF | 0.828 | y = 18.01x - 670.24 |
| | RT-HR | 0.2434 | y = 5.8901x - 161.19 |
| | RT-$O_2$ | 0.4628 | y = -1.2997x + 52.181 |
| **CROSSBREDS** | Amb T-TotalEL | 0.9537 | y = 122.49x – 3500 |
| **(KS/KF)*** | RT-RF | 0.9458 | y = 59.669x - 2271.7 |
| (38.6 to 40.1°C) | RT-HR | 0.9578 | y = 12.571x - 419.21 |
| | RT- $VO_2$ | 0.7958 | y = 0.5539x - 20.836 |
| | THI-DMI | 0.7275 | y=1.4055x-65.861 |
| | THI-DMI/100kg | 0.5018 | y=-0.0135x+4.3494 |
| | Tmax-DMI/100kg | 0.0408 | y=-0.007+3.4768 |
| **SAHIWAL*** | RT- RF | 0.828 | y=18.01-670.24 |
| (38.3 to 39.7°C) | RT- HR | 0.2434 | y=5.8901x+161.19 |
| | RT- $VO_2$ | 0.4628 | y=-1.2997+52.181 |
| | Temp- EvT(sk+P) | 0.0796 | y=103.36x-2581.9 |
| | THI/Pv | 0.9533 | y= 8.8349x-629.29 |
| | THI/ev.loss | 0.9452 | y=11.192x-781.78 |
| | Amb.T/Pv | 0.9795 | y=9.0214x-299.5 |
| | Amb.T /ev.loss/ps | 0.9756 | y=11.454x-365.07 |

*All calculations were made from original data recorded. Data on pulmonary volumes were corrected for Standard Temperature, Pressure, Dry air (STPD).*

## 4.2 Animal Reproduction and THI

Reproductive functions of Zebu Cattle, Crossbreds and buffaloes were analyzed for impact assessment due to T max/ THI changes and rise in temperature (1995-2001). The reproduction of cattle and buffaloes was negatively impacted by rise in temperature particularly during summer. Relationship with THI (Table 2) indicated that rise in THI mainly due to ambient temperature rise impacts animal reproductive functions adversely. Estrus symptoms are less prominent or remain silent and conception of animals are negatively impacted.. Different livestock species have different sensitivity to seasonal variations and temperature changes. The sensitivity of buffaloes was observed to be higher than either Zebu or crossbreds.

**Table.2.** THI and Reproductive functions

| BREED | PARAMETERS | $R^2$ | EQUATION |
|---|---|---|---|
| | | | |
| **Murrah** | THI-Heat Exp. | 0.3238 | y = 0.2998x2 - 6.4984x + 102.27 |
| | THI-Preg | 0.4308 | y = -0.4166x2 + 56.901x - 1813.9 |
| | | | |
| **Sahiwal** | THI- Heat Exp.(%) | 0.5938 | y = -0.0089x2 + 1.4637x - 50.359 |
| | THI-No.Preg. | 0.704 | y = -0.0131x2 + 1.6908x + 25.77 |
| | THI-% Preg. | 0.5593 | y = -0.0146x2 + 2.3074x - 80.775 |
| | THI-ConcR (%)0.2462 | | y = -0.0658x2 + 6.7178x - 95.904 |
| | | | |
| **KF** | THI-Preg | 0.1234 | y = 0.0037x2 - 1.1922x + 164.8 |
| | THI-CR (%) | 0.0065 | y = 0.0038x2 - 0.5222x + 63.54 |
| | THI- Heat Exp (%) | 0.1539 | y = 2.2748x2 - 38.822x + 235.37 |

**4.3 Temperature Coefficients and the Van't Hoff Arrhenius effect on physiological functions**

The changes in physiological functions were measured in cattle and buffaloes and were related to environmental temperatures as prevailed at Karnal. These changes were analyzed for sensitivity of individual animals and species variability which indicated that non-adapted species / breeds exhibit higher magnitude of change than adapted breeds. To indicate the speed of change in physiological functions with rise in temperature the Van't Hoff Arrhenius effect ($Q_{10}$) was calculated for Sahiwal, crossbred and buffalos in relation to T max 20°C and 36°C and results presented (Table.3). The findings indicated that the speed of physiological responses doubles or trebled for an increase of 10°C in temperature. Since rise in temperature increases animal energy expenditure/ Oxygen consumption and animals require extra energy for heat dissipation, therefore maintenance of thermal balance during summer or hot-humid conditions particularly under climate change scenario will require an extra energy expenditure affecting animal functions and productivity negatively. The decline in milk production will be sharp in non adapted livestock mainly due to direct climatic effects as most of the animals will not be able to maintain their thermal balance under natural conditions due to inadequate heat dissipation. The crossbred cattle and buffaloes are likely to suffer more than Zebu adapted to higher heat loads particularly in water scarce areas.

**Table. 3: Van't Hoff Arrhenius Coefficients ($Q_{10}$)**

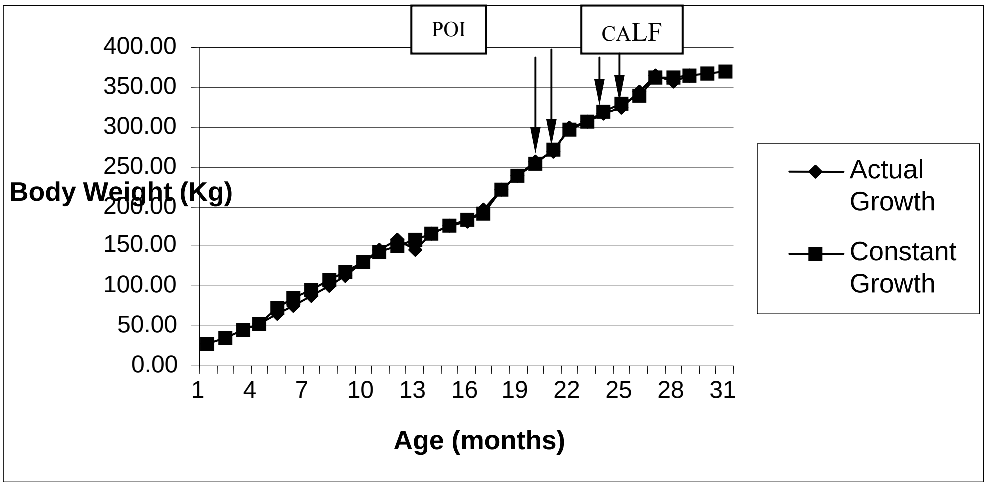
| Parameters | Karan Fries | | Buffalo | | Sahiwal | |
|---|---|---|---|---|---|---|
| | 20°C | 36°C | 20°C | 36°C | 20°C | 36°C |
| **Respiration Rate/min** | 44 | 65.5 | 25 | 65 | 25 | 62 |
| **$Q_{10}$** | ***1.245*** | | ***1.556*** | | ***1.532*** | |
| **Heart Rate/min** | 62 | 77 | 57 | 75 | 58 | 74 |
| **$Q_{10}$** | ***1.135*** | | ***1.7*** | | ***1.52*** | |
| **Rectal Temp. (°C)** | 38.9 | 39.3 | 37.9 | 39 | 38.2 | 38.9 |
| **$Q_{10}$** | ***1.006*** | | ***1.018*** | | ***1.011*** | |

## 5.0 Impact of Climate change and THI on physiological functions.

### 5.1 Animal Growth

Information on Indian livestock with specific reference to physiological functions and impact of climate change and/or due to extreme weather changes on growth and milk production of Indian livestock is not available. In the present study, therefore, sensitivity of Zebu and Holstein Friesian crossbred cows to changes in temperature (Tmax, Tmin) and THI have been analyzed. Animal growth and milk production records from January 1994 to October 2006 at the Institute and climatic records available for Karnal from Central Soil Salinity Research Institute, Karnal; NDRI, Karnal and IMD, Pune were used for analysis and algorithm development.

The growth gradients and growth constants of animals were calculated for both accelerating phase and post point of inflection phase and relationship with Tmax, Tmin and THI were analyzed. The time to reach puberty and time lapse due to decline in growth rate were also computed. The results indicate a negative impact of THI rise on animals growing at higher rates (500g/day or more) day than slow growing (300-400g/day) cattle. The crossbreds were more sensitive to rise in THI than either Zebu cattle or buffaloes. Time to attain puberty was observed to prolong from 5 to 17 days due to decline in growth rate at high temperatures (Figure.3). Crossbreds and buffaloes are affected more than Indigenous livestock. Due to higher sensitivity of crossbreds and buffaloes to temperature rise than indigenous cattle; a rise of 2-6 °C due to global warming will negatively impact growth, puberty and maturity of crossbreds and buffaloes and time to attain puberty will increase by one to two weeks (Figure.3)




POI= Point of inflection

**Fig.3:** Impact of Temperature Change on Growth & Puberty (Cattle)

### 5.2 Milk production: crossbred cows

Milk production records of different locations and climatic records were used for analysis and algorithm development. Algorithms for milk production decline were validated on high and low producing crossbreds during 2005-2006 at the Institute. The climatic elements that influenced milk production of crossbred cows were dry bulb and wet bulb temperatures and THI. The $R^2$ was were very low for cool period and actual effect on milk production of HF crossbreds was minimum particularly when average THI was less than 70. THI or climatic conditions had a relatively small effect on milk production of crossbreds in the months of Jan, Feb and March, but in the month of April when temperature of the day and night was higher; the relationship improved and higher $R^2$ value was observed. The average THI influence on milk production was more than that of either THI -1 and/or THI-2. Regression analysis for milk production and Tmax during cool experimental period for high producing cows indicated a low relationship with Tmax ($R^2$=0.130) and difference between T max and T min. THI1 and milk production of crossbred cows during hot period (April -July) had a strong relationship ($R^2$=0.705) indicating that morning THI is significantly correlated with total milk production in high producing Holstein cross cows. A change in THI during this period was also significantly correlated with change in milk production as is reflected by a moderate relationship ($R^2$=0.46) but change in milk production and change in THI were only 17% related. Regression between Tmin and milk production was found to be strong ($P<0.0001$) as indicated by $R^2$ square ($R^2$ =0.661) in high producing KF cows but was very weak in low producing cows ($R^2$=0.012). A relationship with difference between T max and T min were also moderately related with milk production of high KF ($R^2$ =0.377). Therefore, THI and change in THI though related with milk production in high producing cows had a weak relationship in low producing cows. In high producing crossbred cows both min and max temperature higher than 22°C were observed to have a moderate ($R^2$=0.461) but very significant ($P<0.001$) relationship with milk production. This indicates that milk production of Holstein Friesian crossbred cows producing more than 15 liter milk under hot weather conditions are not only affected by temperature changes but also rise in Tmax and Tmin above 22° C significantly influenced milk production. The potential direct effects of possible climate change and global warming on summer season milk production of crossbred cows were evaluated using widely known global circulation model UKMO to represent possible scenarios of future climate. Decline in milk production were observed due to warming effects mainly due to rise in stress level (THI change) of crossbred cows.

### 5.3 Milk production: buffaloes

The impact of temperature rise/ change was assessed on milk production of Murrah buffaloes and a decline in milk production was observed with a rise in THI and temperature (Fig 4 and 5).Analysis of the potential direct effects of climate change in 2020/2050 and global warming on summer season milk production of Murrah buffaloes indicated that a rise of 1.0 or1.2° C during March–August for India (Region 23- HADCM3 A2/B2 scenario) will marginally affect milk production but temperature rise of more than 2° C over existing temperatures for time slices 2040- 2069 and 2070-2099 will cause higher incidence silent estrus, short estrus and decline in reproduction efficiency of buffaloes. Animals with limited water access will experience warming effect more than that of buffaloes dissipating heat by water wallowing.

Fig.4: Milk Production Vs THI in Murrah Buffalo

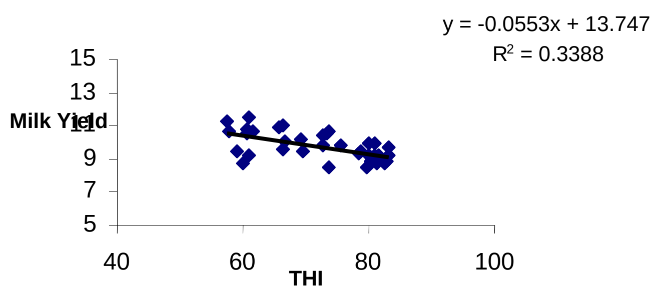
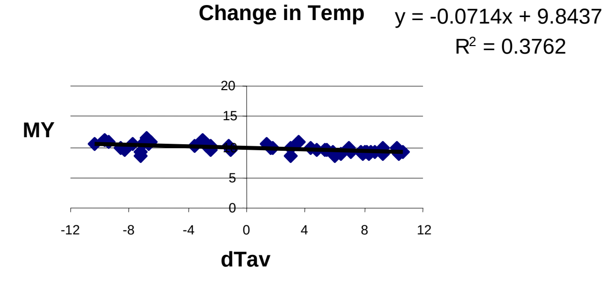



Fig.5: Sensitivity of Buffalo Milk Production to Change in Temp



## 6.0 Effect of extreme events on milk production

A sudden rise in T max during summer and a fall in T min cause a negative impact on milk yield of cattle (Fig.6) and buffaloes (Fig.7). The T max increase (>4°C) than normal during summer and T min decline (>3°C) during winter (Fig.7) was observed to negatively impact milk production in crossbred cattle and buffaloes. The decline in yield varied from 10- 30% in first lactation and 5-20% in second and/ or third lactation. The extent of decline in milk yield were less at mid lactation stage than either late or early stage.

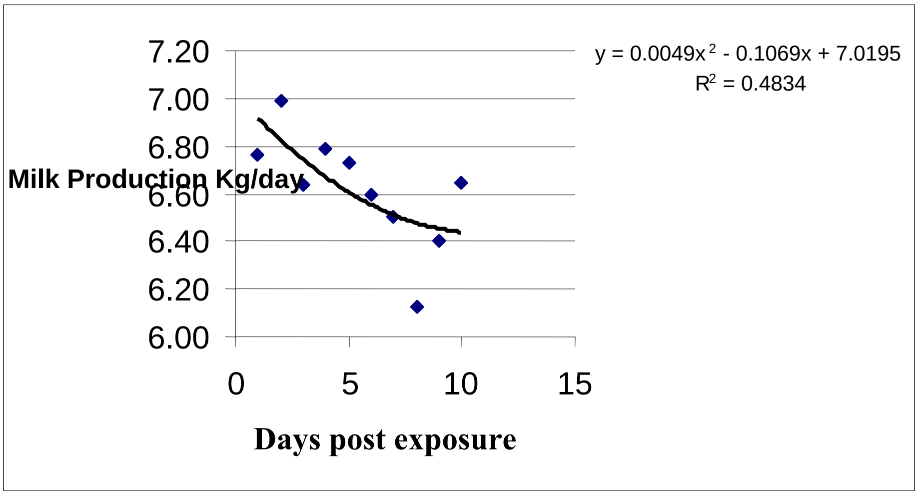



**Fig. 6:** Effect of heat wave on milk production of crossbred cows during summer

The negative impact of sudden temperature change i.e. cold wave or heat wave on milk yield of buffaloes were not only observed on next day of extreme event but also on the subsequent day(s) after extreme event, thereby indicating that T max increase during summer and Tmin decrease during winter cause short to long term cumulative effect on milk production of buffaloes. The return to normal milk yield took 2-5 days with a variable response in individual buffaloes. The decline in milk yield and return to normal yield after an extreme event was also dependant on subsequent day(s)T max and Tmin. The $R^2$ was non- significant and very low for cool period observed during Feb- April/Sept-Nov and actual effect on milk production was minimum. This indicated that low THI (<75) had a relatively small effect on milk production performance. The lactation period of buffaloes were shortened by several days (3-7 days) during extreme summer when THI was more than 80. The expression of estrus and reproductive functions were also negatively impacted. Excessively distressed buffaloes with higher rectal temperature (more than 40 °C) did not exhibit estrus or exhibited estrus symptoms for short duration that often remained undetected.

**Fig.7**: Effect of cold wave on milk production of Buffaloes during winter

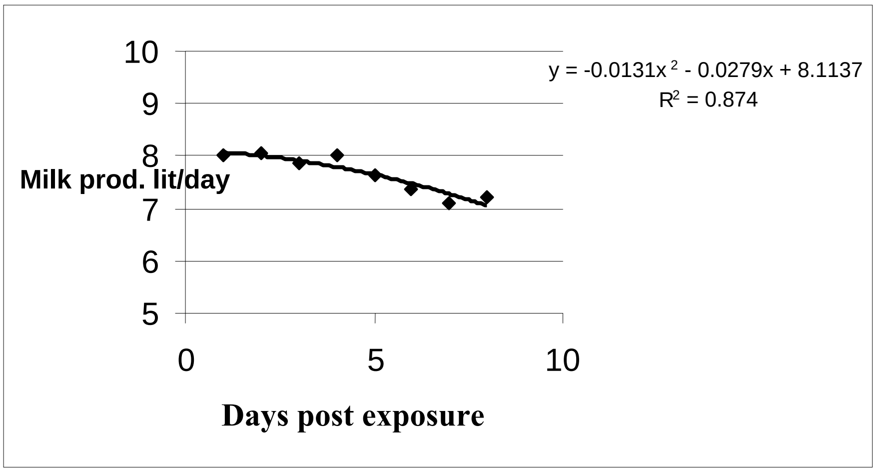



**Table-4: Heat Expressed and Conception rate in Buffaloes (%)**

| Months | THI | % Heat Express | % Conception Rate |
|---|---|---|---|
| January | 59.42 | 7.58 | 41.09 |
| February | 62.94 | 7.77 | 40.58 |
| March | 68.62 | 7.81 | 44.23 |
| April | 75.72 | 6.34 | 47.34 |
| May | 80.91 | 4.24 | 33.63 |
| June | 81.22 | 3.42 | 32.97 |
| July | 77.58 | 5.26 | 30 |
| August | 77.19 | 8.22 | 36.07 |
| September | 77.67 | 10.17 | 44.65 |
| October | 72.93 | 15.39 | 42.44 |
| November | 62.98 | 11.82 | 40.63 |
| December | 58.77 | 11.97 | 38.56 |

**7.0 Micro studies: Impact of temperature rise on Physiological functions**
**7.1. Body temperature and Heat storage**

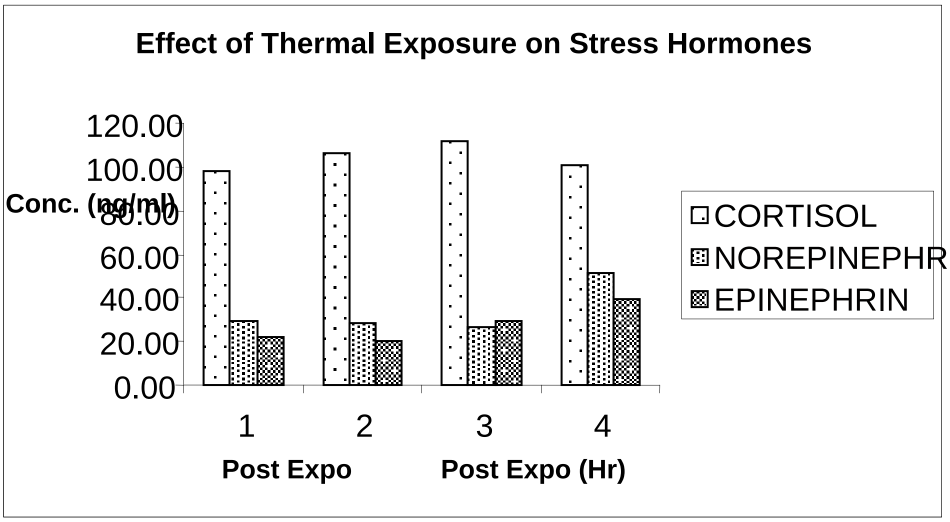
In order to study impact of temperature rise, cattle and buffaloes were exposed under ambient cold and hot conditions. Animals were also exposed in climatic chamber at 45°C for 4 hours. The physiological reactions of cattle and buffaloes increased due to exposure at $45^0$C in chamber and at ambient temperatures. At maximum core temperature of $41^0$C at 2 h and 4 h exposure of buffalo heifers, the heat storage was found to be 4809.42 kJ.Kg/°C, and 4197.31 kJ.Kg/°C, respectively.. The results showed a strong positive correlation between heat storage and Rectal temperature with total variance of $R^2$ = 0.8062 after 2 h exposure and $R^2$ = 0.4256 after 4 h exposure at $45^0$C.

## 7.2Thermal changes and Interaction between stress hormones, free radicals and immunity

### 7.2.1 Thermal stress and stress hormones

Epinephrine, Norepinephrine and Cortisol levels were measured in buffaloes and cattle to study changes induced due to thermal exposure. The level of Cortisol, epinephrine and Norepinephrine declined or increased due to thermal exposure at different hours of exposure. Serial sampling during acute thermal exposure of buffaloes at 45°C found no significant change in cortisol hormone levels but NE and E increased **(Fig.8).** A decline in these hormones was observed in the afternoon as compared to morning levels.
Thermal stress responses were studied on in vitro cultured Lymphocyte in relation to proliferation and interleukine production. Lymphocyte cultures grown for 72 hours were exposed to 45 °C for 4 hours. The cultures grown in presence of Epinephrine and Norepinephrine were affected by thermal exposure. There was a decline in IL1$\alpha$ and IL1$\beta$ indicating that thermal exposure affect immune response.

**Fig.8**. Effect of Thermal Exposure on Stress Hormones in Buffaloes




### 7.2.2 Animal Immune response- Lymphocyte proliferation studies

Jugular vein blood samples were collected during exposure of buffaloes. The Lymphocyte Proliferation Assay was performed using whole blood method and tritiated thymidine was used for counting activity incorporated by dividing lymphocytes. The stimulation index oflymphocytes due to mitogen at pre exposure, 2 h and 4 h exposure at $45^{0}$C in buffalo heifers were found to be 1.72$\pm$0.30, 1.36$\pm$0.34 and 1.87$\pm$0.32 The values of SI were found to be statistically non-significant between groups indicating that exposure did not cause a significant change in LPI.

## 7.3 Heat Shock Protien 70 and Heat Exposure:

**HSP70 in Plasma of exposed buffalo heifers: (*In-vivo* experiment)**

HSP70 and IL2 were assayed in the plasma of the exposed (45°C) buffalo heifers at the pre exposure, 2 h and 4 h exposure. The mean HSP70 content in the plasma of buffalo heifers was found to be 1.42±0.10, 2.25±0.54 and 1.76±0.30ng/ug of protein at pre exposure, 2 h and 4 h exposure, respectively. The difference was found to be statistically significant between the groups ($P<0.001$) and also within the periods. Between the periods effect was significant ($P<0.001$) but a non- significant difference was observed between pre exposure and 4 h exposure.

The interrelationship between HSP70 and rectal temperature of the exposed buffalo heifers indicated that prior to exposure, buffalo heifers had a low HSP70 (Y= -0.2201X + 9.884, $R^2$=0.4192) but after 2 h exposure at 45$^0$C a rise in HSP70 level was observed in plasma due to rise in rectal temperature. The interrelationship between HSP70 and heat storage was found to be a negative at both 2 h and 4 h exposure at 45$^0$C.

### 7.4 Interrelationship between lymphocyte proliferation, heat shock protein 70 (hsp70) and interleukin – 2 (il-2):

***i. In-vivo* study:**
The HSP70 concentration increased in plasma after 2 h exposure and the IL2 level in plasma decreased and Lymphocyte proliferation decreased. The concentration of IL2 and SI was highest during the pre exposure period, but HSP70 concentration was lowest prior to the exposure of heifers.

***ii. In-Vitro* Study:**
In order to see effects of temperature on lymphocytes of buffaloes, the cells were separated through density gradient centrifugation method and given three temperature treatments i.e. one part was treated with 38$^0$C for 48 h and further at 45$^0$C for 3 h, 2$^{nd}$ part was suddenly exposed at 42$^0$C for 3 h without any prior exposure at milder temperature and 3$^{rd}$ part was exposed at 45$^0$C for 3 h. HSP70 was found to increase 2 fold in the I $^{st}$ temperature treatment than the 2$^{nd}$ temperature treatment. A strong positive correlation was observed between HSP70 and IL ($R^2$ =0.0.99). The average HSP70 in cells were found to be 32.74±7.77, 15.51±4.29, 11.05±1.68 ng/µg protein in the I $^{st,}$ 2$^{nd}$ and 3 $^{rd}$ group, respectively. The corresponding average IL-2 was found to be 6.00±1.57, 4.04±0.69 and 3.51±0.87 pg/µg protein.

### 7.5 Effect of catecholamines and thermal exposure on lymphocyte proliferation, IL-1 α & β in buffaloes

The effect of catecholamines (epinephrine/norepinephrine) and thermal exposure on in vitro buffalo Lymphocyte Proliferation was also studied using fresh blood of healthy 2- 21/2 years old Murrah buffalo heifers. Lymphocyte proliferation assays were performed using whole blood and cells were incubated with Epinephrine and Norepinephrine (1, 1.5,2 ng/ml) at 37$^o$C with 5% $CO_2$. Cells were counted after 72 hrs of incubation and LPI was calculated. Thermal stress effect on the cultures was observed after exposure at 45$^0$C for 4 hr after 72hrs of incubation. The cells were separated from media and media was used for analysis of IL-1α & β by ELISA kit. Lymphocyte proliferation Index decreased in responses to Epinephrine and Norepinephrine ($P<0.01$). Concentration of Epinephrine and Norepinephrine (1, 1.5,2 ng /ml) had no distinguishable effect on LPI. IL-1α and IL-1β levels when compared with control in supernatant (exposed to 45°C) were low ($P<0.01$ and $P<0.05$, respectively). There was a significant positive correlation between LPI and IL-1α (r=0.80; $P<0.01$) and between LPI and IL-1β (r=0.78; $P<0.05$). The study indicated that lymphocyte proliferation in vitro and IL-1α & β levels were affected by catecholamines and thermal exposure. Further the levels of catecholamines had significant ($P<0.01$) negative effect on LPI indicating that catecholamines levels modulate immunity through IL-1α and IL-1β in buffaloes.

**7.6 Impact of high temperature and humidity on core and skin surface temperature of lactating Zebu and crossbred cows.**

The impact of high ambient temperature and humidity on core and skin surface temperatures was observed in ten lactating Zebu (Sahiwal & Tharparkar) and crossbred (Holstein Friesian x Tharparkar) cows. The macro climatic conditions were recorded at 7.22 hr and 14.0 hr. and Temperature humidity index (THI) was calculated from dry bulb ($T_{db}$) and wet bulb ($T_{wb}$) at respective hours. THI of morning was 76.7 (74-79) and afternoon THI was 82.4 (73.4-85.2). The THI values during morning ranged between 74- 81 at 08.00 hrs and in afternoon at 15.00 hrs between 82-87 in sheds. The rectal temperature (RT) was recorded to represent core temperature and skin as shell temperature. Skin surface temperature (ST) was recorded (infrared thermometer) at 16 different locations at 8.00 and 15.00 hr. At 08.00 hrs, the mean RT and ST of crossbred cows were 38.59±0.04 ºC and 32.18±0.18ºC when THI was more than 76 and wind velocity was higher than 325 fpm. The respective values for RT and ST in Sahiwal cows were 38.43±0.57ºC and 31.26±0.38ºC (THI=75 and WS=180 fpm); and in Tharparkar 38.59±0.07ºC and 31.90±0.19ºC (THI=80, WS=85 fpm). Between breeds, the difference in ST during morning was significant ($p<0.05$). In afternoon, at 15.00 hrs there was a significant ($p<0.01$) increase in mean THI. The mean RT and ST of crossbred cows at 15.00 hrs were 39.51±0.07ºC and 34.57±0.1ºC (THI=85, WS=500 fpm); 39.12±0.09 ºC and 34.25±0.2ºC (at THI=84, WS=800 fpm) for sahiwal cows; & 39.18±0.05ºC and 35.32±0.25 ºC (THI=86, WS=85 fpm) for Tharparkar cows. The wind velocity was observed to influence surface and core temperatures of lactating cows more in crossbreds than Tharparkar or Sahiwal. The change in RT and ST was significant ($p<0.01$) during the afternoon and breed effect was also significant ($p<0.01$) on RT and ST. This study revealed that a significant increase in wind speed ($p<0.01$ at 1500 hrs) helps in mitigating thermal heat stress. The results further confirm that the crossbred cows are likely to be impacted by a high THI. Under such stressful situations, both crossbreds and Zebu will be benefited by wind velocity change due to high convective heat loss.

**7.7 Temperature change and feed intake trends**

In order to assess impact of temperature on feed intake of cattle and buffaloes data pertaining to Tharparkar, Sahiwal, crossbred cattle and buffaloes were reanalyzed. The analysis of feed intake and trends in T max and T min indicated that crossbred and buffaloes are sensitive to temperature rise observed during summer and rainy season. The Dry matter intake declined with increase in Tmax/ Tav/ THI during summer (hot)/ rainy (hot-humid) season and increased with Tmin decline during winter. Animals in different physiological states/ production ware affected differently and magnitude of change varied. The interrelation between THI/Ambient temperature and Dry Matter Intake for Karan Fries at Karnal and Buffaloes at Hissar are as follows:

Karan-Fries (Temp. 23.8- 32.8°C) y = -0.0846x2 + 4.2641x - 39.677, R2 = 0.5774

Buffalo (THI 81.8-88.95) $y = 0.0868x^2 - 15.022x + 662.26$, $R^2 = 0.5751$

## 8.0 LIVESTOCK: GREENHOUSE GASES EMISSIONS

**8.1 Inventory of enteric methane emission for 2006: IPCC methodology**

In this study an attempt has been made to present inventory of enteric methane emission for 2006 and reduce uncertainty in enteric methane emission of Indian livestock by following IPCC guidelines on good practice guidance and uncertainty reduction. Enteric Methane Emission of 160.495 million Indigenous Cattle, 24.68 million Crossbred cattle, 97.92 million Buffaloes, has been estimated using Tier 2 methodology of IPCC. Tier 1 methodology of IPCC and default factors have been used for estimating enteric methane emission for 61.46 million Sheep and 124.35 million Goats and 15.72 million equines, Pigs and other animals.

The country specific methane emission factors were developed based on average methane emissions in expired air (0.01 to 0.08%) and eructation level (0.1 to 0.25%). The methane emission in expired air of growing, adult cattle and buffaloes maintained on different feeding regimens at the Institute were precisely monitored by the Open circuit method over different time intervals after feeding. The developed coefficients for Zebu, crossbreds and buffaloes were used for calculating enteric methane emissions. Large uncertainties exist in the estimates of livestock enteric methane emission estimates put forward by different investigators mainly due to variations in livestock breeds, body weights, growth, feed quality& resources and their digestibility, milk production, emission coefficients etc. In the present study, therefore, body weights of livestock were categorized according to breed(s) and population in a state. The livestock population was also categorized for stall fed, grazing at small or large area, work and activity. The milk production and composition of milk of different breeds of cattle have also been accounted. The information on feed intake, digestibility, metabolizable energy, feedstuffs type and emission coefficients was also taken in to consideration for calculating emissions from different age groups of animals.

The total methane emitted due to enteric fermentation and manure management of 485 million heads of livestock was worked out at 9.32 Tg/annum for the year 2003. The major contributors to methane emission in 2003 were Indigenous, Crossbred Cattle and Buffalo accounting 41%, 8%, and 40%, respectively. In the year 2003, more than 56 million working oxen and buffalo males contributed 1.02Tg methane. Lactating animals comprising of Buffaloes and Cattle contributed 3.077 Tg with a major share of 1.88 Tg from buffaloes. The results further indicated that total emission from bovines was 7.36 Tg/year and contribution of buffaloes was 3.48 Tg/year, indigenous 3.17 and crossbred 0.7 Tg/year (Fig 9). The enteric emissions of livestock for the year 2006 were estimated based on the changes in livestock population structure (1997-2003), Livestock Census 2003. The emissions for the year 2006 were estimated at 9.39 Tg/annum from both enteric emissions and manure management. In 2006, the contribution of Indigenous Cattle to enteric emission was 38% as against 41% in 2003 due to decline in unproductive indigenous cattle and working oxen population by 2006. The contribution of buffaloes to enteric methane emission was 43% in 2006, higher than other livestock due to rise in buffalo population.

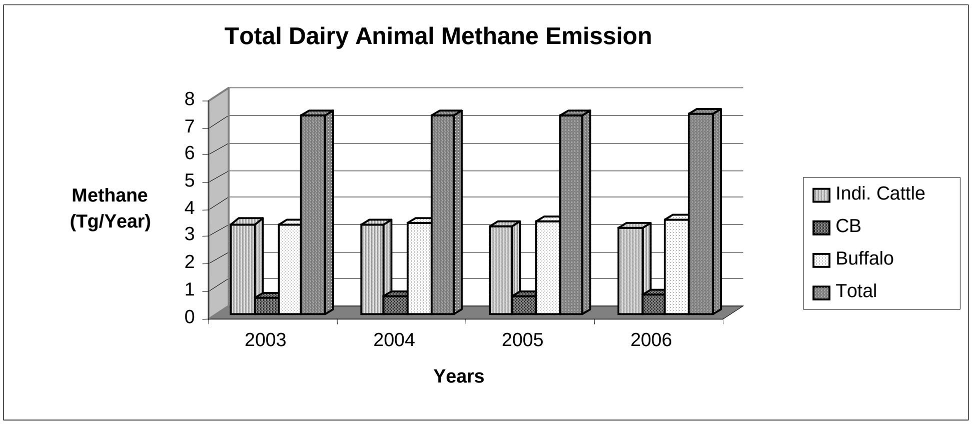



Figure 9: Values of Methane Emission have been calculated taking into account breed body weight, feed differences, methane emission coefficients (Network NDRI) and other parameters required for IPCC Tier 2 methodology.

GE = [((NEm+ NEmobilized + NE a + NE l + NE p) / {NEma /DE}) + (NEg / {NEga /DE})] / DE / 100)

Annual Methane Emission (Kg/Year) = ([GE × Ym] / [55.65 MJ/kg CH4])x365xPopulation

### 8.2 Greenhouse gases inventories – uncertainty reduction

Considerable uncertainties exist in the emission estimates of green house gases from Indian livestock. These uncertainties arise mainly due to use of emission coefficients either IPCC default or in vitro. Since Indian livestock production system is crop residue based, the IPCC coefficients, their estimates and measurements are related to European livestock and western intensive livestock production system making use of concentrates and limited roughages. In the present study an attempt was made to generate Indian livestock specific emission coefficients for livestock enteric Methane production by undertaking animal specific continuous and intermittent investigations under different feeding schedules.

#### 8.2.1 Methodology and Methane measurement system

The Enteric Methane emission measurement device consisted of a methane analyzer (ADC, UK) in samples of expired air collected in Douglas bag/ or exhausted air at constant rate from animal face- mask or chamber with the help of a pump. The methane production was calculated from average concentration, flow rate and time factors and expressed (L/24 hr) after STPD correction.

#### 8.2.2 Methane emission coefficients

The coefficients developed for Indian livestock based on present investigation indicate lower emission of Methane from rumen fermentation of Indian feeds and fodders (table : 4). The observed values for growing and adult livestock are lower than the values calculated on the basis of IPCC emission coefficients or in vitro methane emission measurements.

#### 8.2.3 Effect of level of fiber in the ration on methane production

In order to study effect of level of fiber in the feed on methane production concentrate mixture comprising GNC, maize and wheat bran (35,30 and 32 parts) was prepared. The concentrate mixture had 12.41% CP and 67.5% TDN. Four substrates were prepared to get 40, 50, 60 and 70% NDF in the diet. Ratio of concentrate mixture and wheat straw was 85:15, 65:35, 40:60 and 20:80 at the respective NDF level. These substrates were incubated for 24 hours to estimate in vitro digestion (one stage) and in vitro gas production. IVDMD (%) was 68.65, 59.62, 48.40 and 39.43, which decreased significantly with the increase in fibre content of diet. IVOMD also decreased from 65.17 (40% NDF) to 35.48 (70% NDF). Total gas produced was 50.69±2.85, 44.99±2.99, 33.87±1.82 and 23.13±1.76 lt/kg DM in the four substrates respectively, which differ significantly ($P<0.05$). When expressed as lt/kg DDM the values were 75.40, 77.53, 70.99 and 61.27. Total Methane produced (lt/kg DDM) also decreased significantly with the increase in fibre level however the percent of methane produced was more and when digestibility of the diet was considered, the values did not vary significantly. The result indicated that percent of methane in the total gas was more when level of fibre was high however total amount was less.

In vivo experiment was conducted on crossbred calves (B wt 250 Kg) and were fed three rations comprising of conc. mix and wheat straw in the ratio of 70:30, 50:50 and 30:70 to get 40,50 and 60 % NDF in the diet. With the decrease in concentrate mix in the diet protein and fat content decreased from 14.80 to 8.28 and 3.16 to 1.70. With the increase in the fiber content, DMI decreased by 30% from 6.32 to 4.47 kg/d. Though the GE content of the diet did not vary, intake decreased significantly. Digestibility of DM and OM was lower in the group III. Though methane production (g/d) was lower in group III by 20% only it was higher per kg DMI as well as per kg DDMI.

**8.2.4 Methane emission reduction: Effect of Fenugreek (Trigonella foenum) feeding in livestock.**

Twelve crossbred steers (2.0- 2.5 years) divided in 2 groups of 6 each, were fed on a diet containing wheat straw and concentrate mixture in the ratio of 60: 40. Group II was supplemented with 100 g raw Fenugreek Seed (FS) in addition to the diet fed in control group (I). Concentrate mixture contained groundnut cake-21, mustard cake- 12, maize- 33, wheat bran-20, rice bran-11, salt-1 and mineral mixture-2 parts having 18.59% CP and 68% TDN. After an adaptation period of 21 days on experimental diets, a 7 days digestibility trial was conducted to determine DM digestibility and methane production. Methane production was estimated by using SF6 tracer technique. Total DM intake in groups I and II was 5.06 ± 0.14, 5.08 ± 0.14 kg, respectively and the variation between the groups was not significant. The DM digestibility in corresponding groups was 65.11 ± 0.79 and 65.68 ± 1.24, with the result digestible DM intake was similar in both the groups. Supplementation of FS reduced the protozoa population in rumen liquor from 14.53x104/ml (I) to 8.42x104/ml (II)( $P<0.05$) and increased TVFA concentration though the difference was not significant. Methane production (g/day) estimated by sulphur hexafluoride ($SF_6$) gas method using 3 representative steers from each group, was 109.31 ± 10.59 and 83.56 ± 11.73 in groups I and II, respectively, and the variation between the groups was not significant. These results revealed that diets supplemented with 2 per cent FS did not increase the palatability as well as nutrient digestibility of ration significantly, however, methane emission from steers as a result of enteric fermentation reduced more than 20 per cent in comparison with control diet. These results also indicated that loss of dietary energy in terms of GE, DE and ME in the form of methane reduced appreciably following the supplementation of diet with fenugreek seeds.

**Table 4** : Methane emission coefficients

| **Animal** | **Age group** | **Av. B.Wt** | **Methane L/24hrs** | **Av. MY(Kg)** |
|---|---|---|---|---|
| Murrah<1yr | 180 | 40.10 | 9.10 | |
| 1-3yr | 290 | 60.75 | 15.30 | |
| Adult NL | 435 | 58.15 | 6.48 | |
| Adult NL | 560 | 65.36 | 21.61 | |
| Adult NL | 630 | 60.27 | 14.47 | |
| Adult lact | 640 | 64.30 | 10.70 | 7.08 lit |
| Adult lact | 640 | 64.50 | 23.94 | 7.60 lit |
| SahiwalGrowing | 150 | 34.45 | 4.42 | |
| Growing | 240 | 34.42 | 7.55 | |
| Adult NL | 340 | 50.87 | 16.49 | |
| Lactating | 375 | 55.05 | 11.25 | 5.00lit |
| Tharparkar 2-3 yr | 175 | 27.39 | 6.98 | |
| >3yr | 245 | 31.08 | 10.44 | |
| Non lact | 420 | 61.74 | 46.41 | |
| Adult lact | 445 | 46.99 | 14.23 | |
| Adult lact | 345 | 51.38 | 9.34 | 8.00lit |
| Karan Fries <1yr | 150 | 39.20 | 8.67 | |
| 1-2 yr | 220 | 50.97 | 16.02 | |
| 2-3 yr | 360 | 50.74 | 10.80 | |
| Adult NL | 425 | 103.08 | 103.08 | |
| Adult lact | 425 | 126.53 | 62.68 | 18.43lit |

## 9.0 Economic losses due to heat stress

An attempt was made to map the THI load at some district level and provide first estimate of economic losses from heat stress in dairy animals at the national and sub-national level. The weekly average THI was computed for 103 stations from normal maximum and minimum temperature and relative humidity. The weekly average THI was computed and worked out at two different levels of threshold, i.e. 72 and 78. Assuming the average weekly THI load to be uniform for all the seven days in a week, the two levels of total THI load for a week were arrived at as follows

(Actual THI -72) * 7 (Load 1)

(Actual THI -78) * 7 (Load 2)

The annual THI Load was sum of the total weekly load over 52 weeks. For the district level mapping of the THI load, the districts of major 19 states in the country were given appropriate value of the THI load out of the computed information for the 103 stations. The map indicates that the annual THI load is above 1000 units in most parts of the country and it is particularly, high in the coastal areas.

The annual milk production loss in each district was computed for buffaloes, crossbred, and local cows. The productivity loss in per unit of THI increase beyond the threshold was taken from the analysis of relationship between milk production and THI, mentioned reported earlier in this report. The in-milk population of dairy animals pertained to 2003 livestock census. Thus, the total annual productivity losses were worked out as follows:

Crossbred: 0.075 liters * Load1 * Number of animals in milk

Local Cows: 0.075 liters * Load2 * Number of animals in milk

Buffaloes: 0.055 liters * Load2 * Number of animals in milk

The state wise results arrived at by averaging the production losses over the districts each state as presented in Table 5:

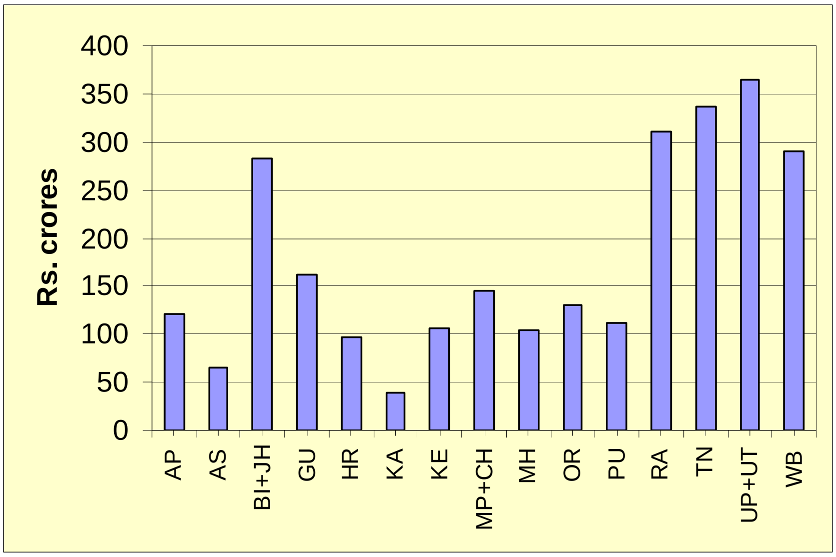
**Table.5.** Annual Loss in Milk Production due to Heat Stress

| States | Crossbred cows | Local cows | Buffaloes | Total annual loss |
|---|---|---|---|---|
| | (liters/animal/year) | | | (million litres) |
| Andhra Pradesh | 104.24 | 15.35 | 11.25 | 89.96 |
| Assam | 95.73 | 21.32 | 15.64 | 40.07 |
| Bihar * | 108.47 | 27.61 | 20.25 | 173.49 |
| Gujarat | 110.70 | 27.40 | 20.09 | 117.83 |
| Haryana | 99.45 | 36.94 | 27.09 | 68.66 |
| Karnataka | 47.70 | 1.32 | 0.97 | 27.86 |
| Kerela | 125.35 | 10.46 | 7.67 | 75.73 |
| Madhya Pradesh* | 91.36 | 15.59 | 11.43 | 110.73 |
| Maharashtra | 79.61 | 8.50 | 6.23 | 78.65 |
| Orissa | 122.20 | 28.00 | 20.53 | 79.05 |
| Punjab | 91.23 | 18.62 | 13.65 | 84.76 |
| Rajasthan | 98.65 | 40.55 | 29.74 | 224.05 |
| Tamil Nadu | 132.86 | 20.93 | 15.35 | 238.64 |
| Uttar Padesh* | 82.75 | 18.76 | 13.76 | 254.30 |
| W. Bengal | 123.93 | 36.50 | 26.76 | 168.28 |
| INDIA | | | | 1832.06 |

* before carving out of new states

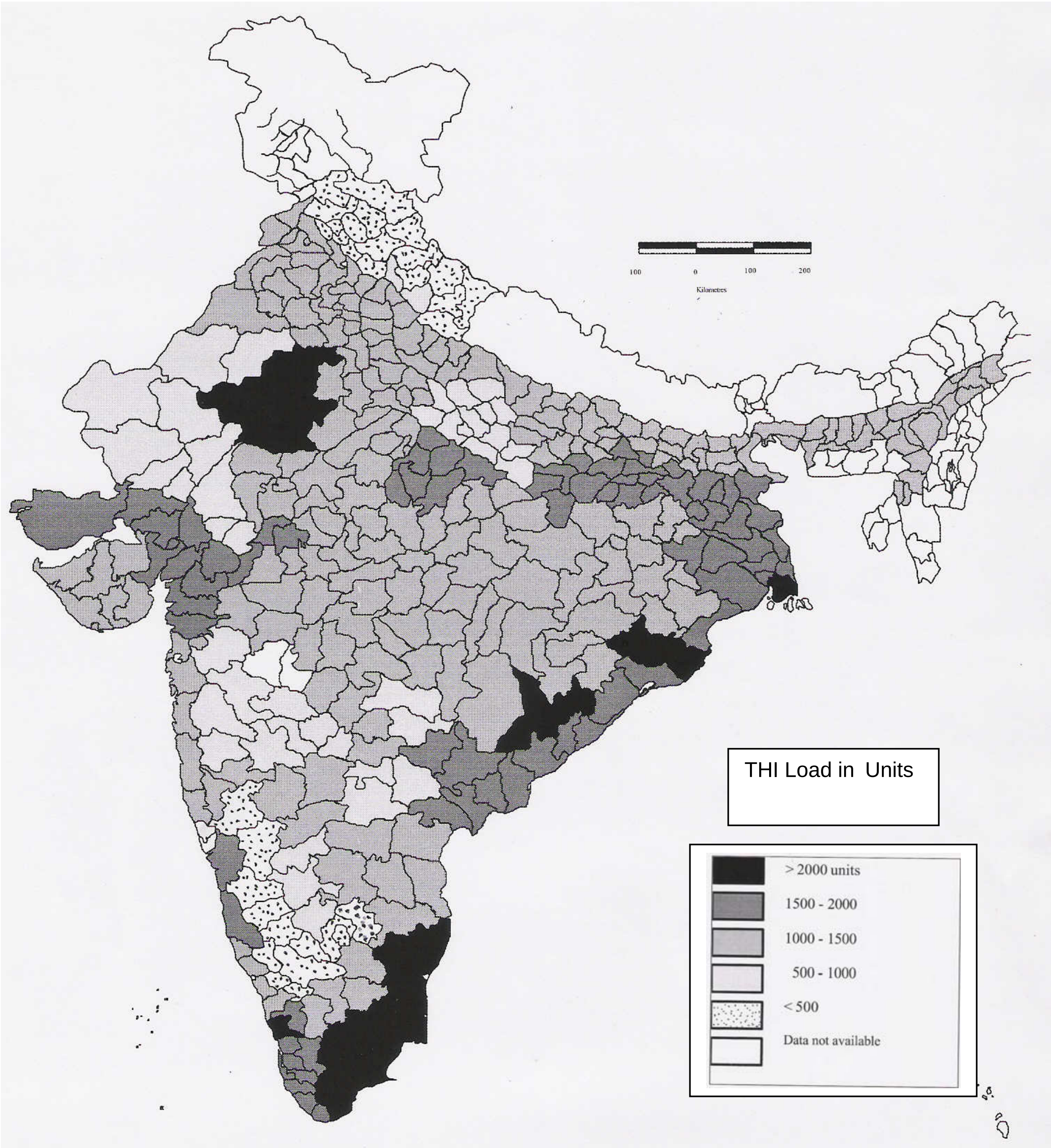
The estimated annual loss at the all-India level is 1.8 million tones, that is, nearly 2 percent of the total milk production in the country. In value terms this amounts to a whopping Rs.2661.62 crores (at current prices). The economic losses were highest in UP (>Rs.350 crores) followed by Tamil Nadu, Rajasthan and W. Bengal (Figure 9).

**Figure 9**. Annual Economic losses in milk production due to heat stress




With likely increase in temperature due to climate change the heat stress in dairy animals would accentuate, thereby further increasing the magnitude of economic losses attributable to heat stress. Also, the high magnitude of losses has implications for the investments in adaptation strategies to alleviate such losses.

**Figure10**. Annual THI Load



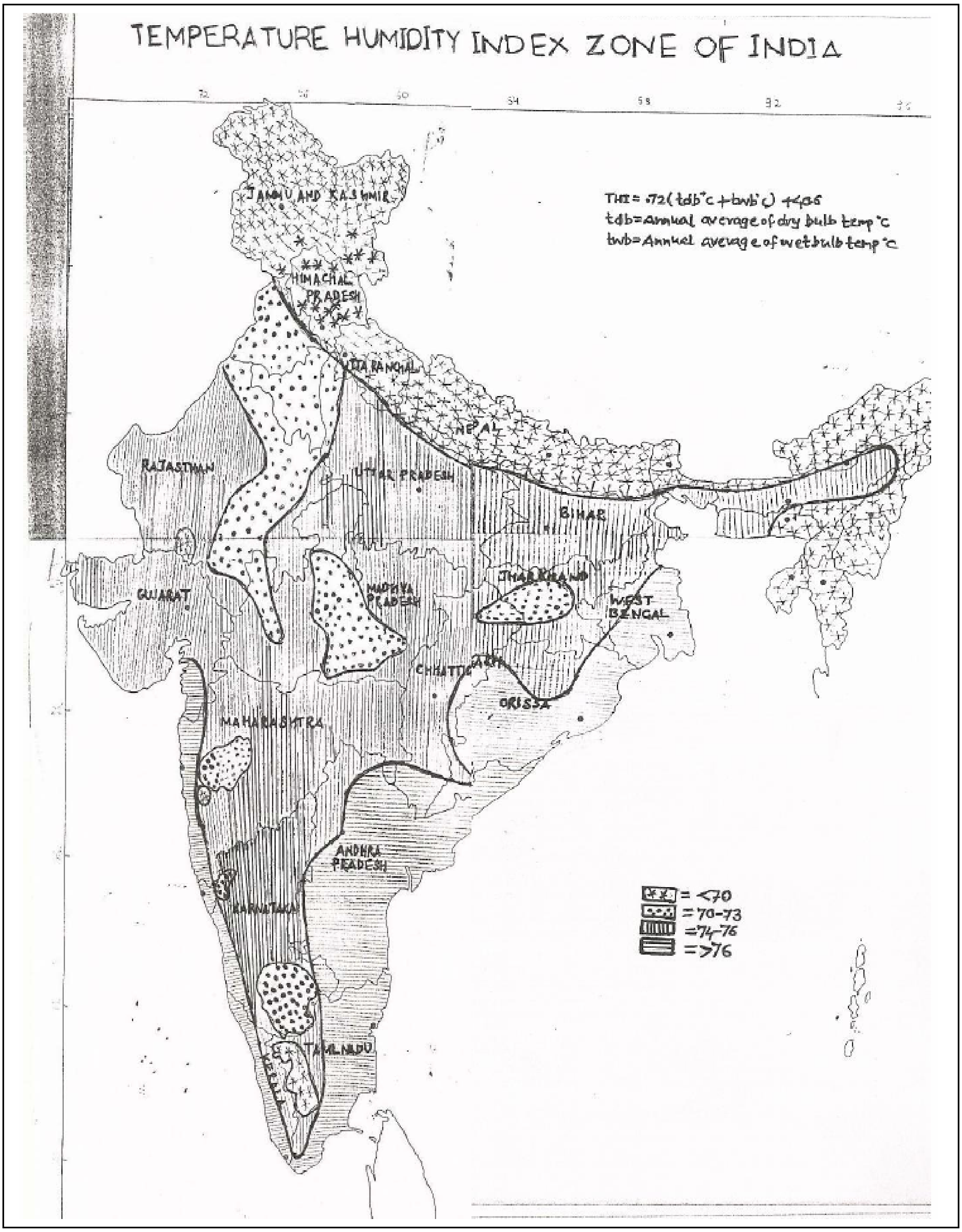
**10. Mitigation of thermal loads: Effect of shelter**

In order to study thermal effects and impact of mitigation measures on livestock production system; eight lactating Sahiwal, Crossbreds and buffaloes were divided into two groups. One group was kept in open with no access to shade with direct solar exposure in animal barn (group-I) and other open to similar conditions but with sheds available to protect in loose housing system (protected).
In crossbred lactating animals the physiological responses increased with the rise in ambient temperature. The respiratory frequency changed from 45 to 67 breaths/min, heart rate 63 to 77/min and rectal temperature 38.61 to 39.33°C in exposed experimental animals (group I). The physiological responses for protected animals (group II) were lower, respective values being 31-45/min, 63-71/min and 37.97-38.81°C during summer season. The changes in physiological responses of exposed animals were mainly due to higher thermal heat load/ solar exposure under open conditions. The surface temperature exhibited circadian variation (27°C-38°C) in both groups during summer and winter seasons. Animals maintained under open conditions had about 2°C lower values than protected group of animals during night hours mainly due to higher wind velocity in open houses during summer season.

In lactating buffaloes a similar circadian pattern was observed in physiological responses and skin surface temperature. The magnitude of change was higher during summer than winter season (fig. 11). The skin surface temperature reached a maximum value of 40.25°C in the after noon in exposed group, which declined to 30°C in early morning (3-4.0am). The physiological responses (RR, HR) and surface temperature were found to be significantly ($P<0.01$) lower during winter in all genotypes of animals. Analysis of data showed a significant ($P<0.001$) positive correlation among physiological responses and ambient temperature. A significant ($P<0.05$) higher heat storage was found in crossbred cows than Zebu where as reverse trend was found in sweating rate i.e. significantly ($P<0.05$) higher in Zebu cattle than crossbred cows and buffaloes. THI and heat storage was negatively correlated with milk production of cattle and buffalos during summer season.

The study concludes that during summer animals require protection from direct solar radiations to reduce direct solar heat exchange. Animals during summer months should be kept in open during cool nights or cool periods to facilitate heat elimination / reduction in thermal load gained during daytime. Cool wind facilitates heat exchange and help in attaining thermal equilibrium during night. However, during extreme winter all animals need to be protected from cold winds and proper housing system with ventilation are necessary.

**Figure11. Temperature Humidity Index Zones of India**



# Central Marine Fisheries Research Institute, COCHIN

**Objectives:**

To study the direct and indirect impact of climate change on marine fisheries using historical data;

To create data base on key environmental parameters indicators for tracking, future assessment and prediction of impact of climate change on marine fishes

To study the impact of climate change on marine fish catch, cross-correlation analysis was carried out between historical Sea Surface Temperature SST), Southern Oscillation Index (SOI) and annual fish catch along the southwest, southeast, northwest and northeast coasts of India for five major fish groups, namely, pelagic, demersal, crustacean, cephalopod and total marine fish catch for the years 1960 - 2004. The following results were obtained:

- Trend in SST showed significant increase at the rate of 0.045$^{o}$ C per decade along the southwest, northwest and northeast coasts and at the rate of 0.095$^{o}$ C per decade along the southeast coast. SST along the Indian coast at different time intervals was mapped to study the trend (Fig.1). ICOADS sea surface temperature data (obtained from ESRL PSD www.cdc.noaa.gov) and 9-km resolution monthly SST obtained from AVHRR satellite data (provided by the NOAA/NASA at http://podaac.jpl.nasa.gov/) was used.
- Demersal, crustacean and cephalopod and total catch showed a negative correlation with SST, resulting in reduced catch in the succeeding year with increase in the current year SST (lag one year) along the northeast coast (Fig. 2).
- Pelagic and total catch showed a positive correlation with SST, resulting in higher catch with one year lag period along the southwest coast (Table 1).
- The total catch showed a positive correlation with increase in SST along the southeast coast. Southern Oscillation Index had a negative influence on SST along the northeast, southeast and northwest coasts.
- Mean sea level variations in Andaman Sea, Indian Ocean, Bay of Bengal and Arabian Sea (Fig. 3) showed an increase of 3.772mm, 2.68mm, 1.086mm and 0.0705mm per year respectively while the global increase is 3.20mm/year. Data obtained from http://sealevel.colorado.edu/

**Fig.1**. SST trend in the Indian Seas during different time periods

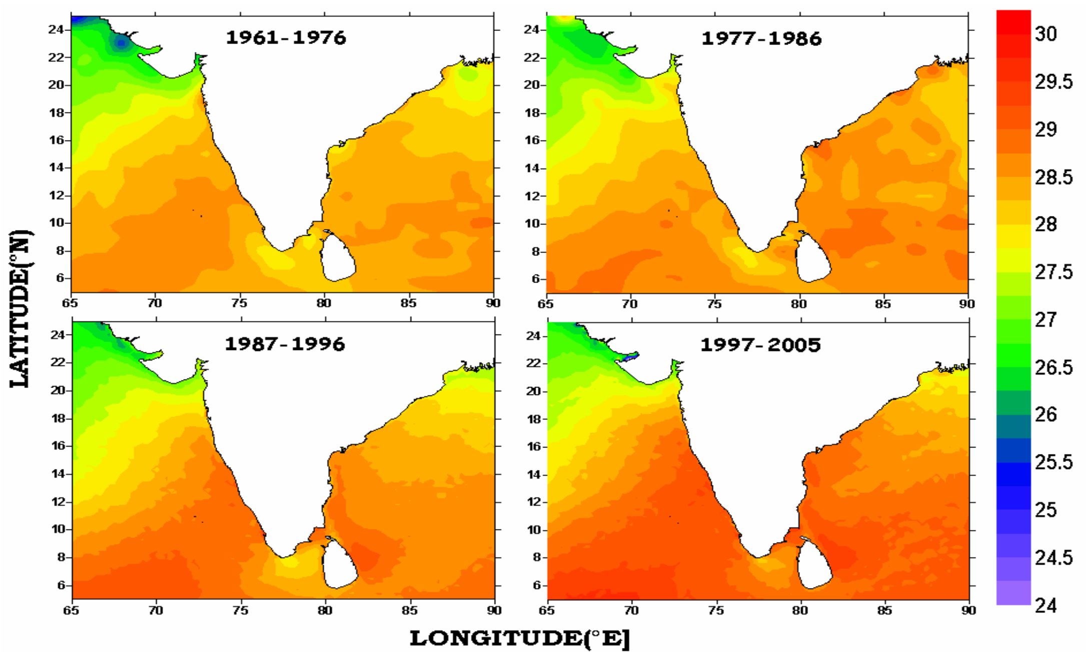
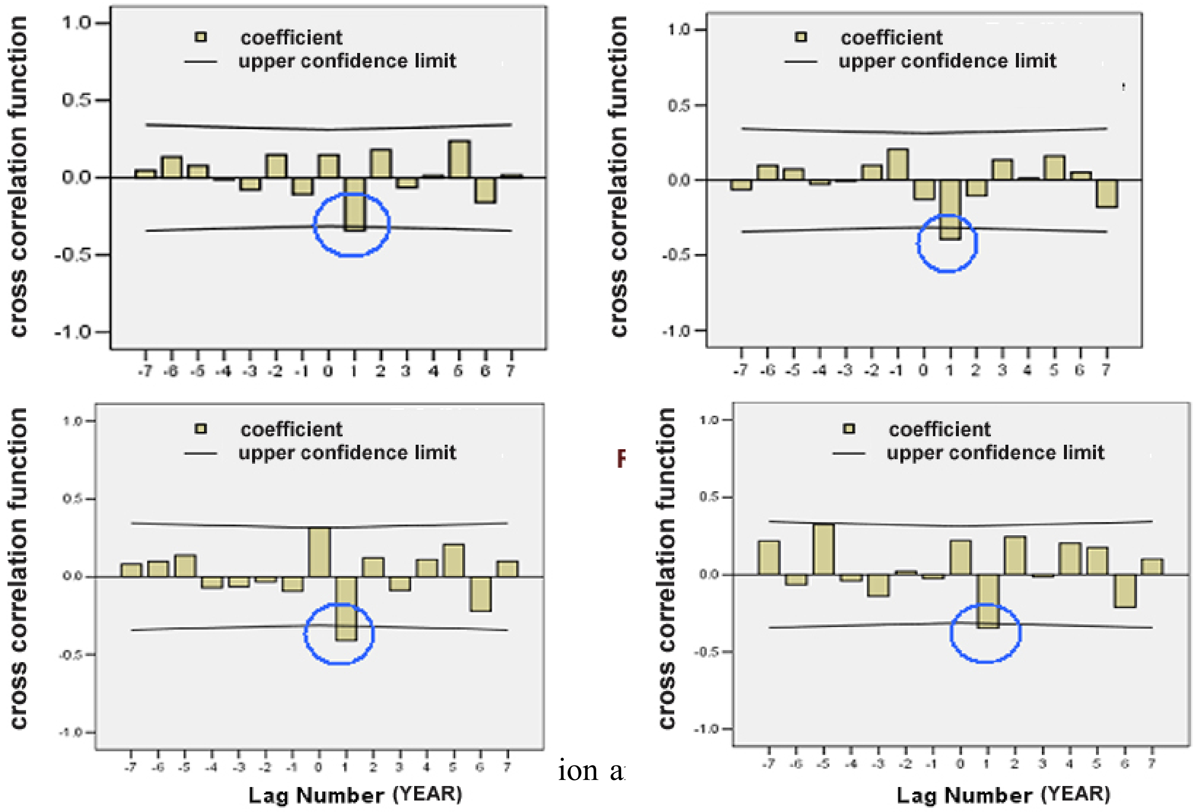


**Fig. 2.** Cross-corrleation function between SST and fish catch along the northeast coast during 1961-2004

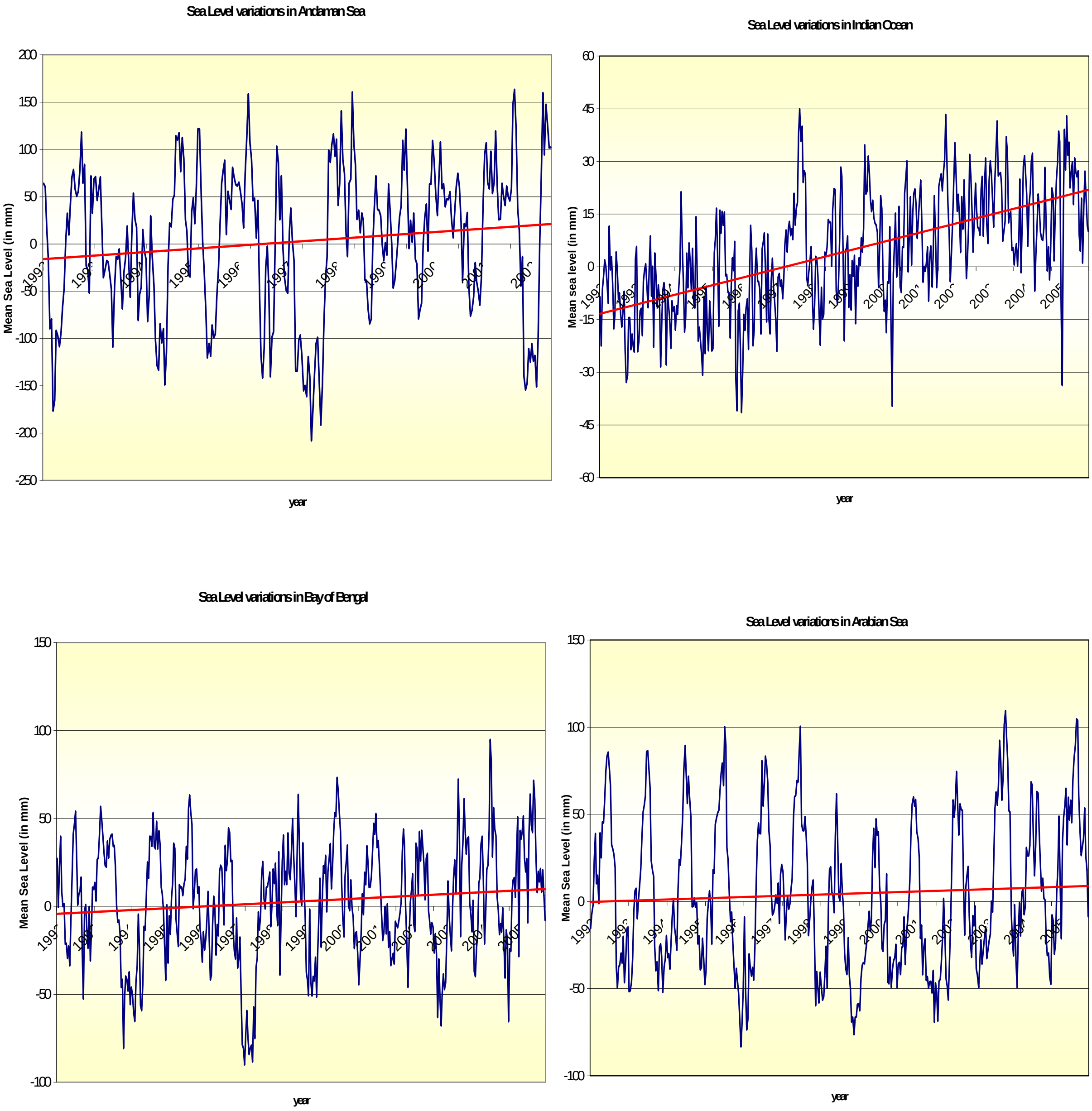



Relationship between SST and crustacean catch along northeast coast

Relationship between SST and cephalopod catch along northeast coast

| Resource | Southwest | Southeast | Northeast | Northwest |
|---|---|---|---|---|
| Pelagic | ✓ (1) positive | No correlation | No correlation | No correlation |
| Demersal | No correlation | No correlation | ✓ (1) negative | No correlation |
| Crustacean | No correlation | No correlation | ✓ (1) negative | No correlation |
| Cephalopod | No correlation | No correlation | ✓ (1) negative | No correlation |
| Total | ✓ (1) positive | ✓ (0) positive | ✓ (1) negative | No correlation |

**Fig. 3.** Trend in mean sea level in Andaman Sea, Indian Ocean, Bay of Bengal and Arabian Sea during 1992 – 2006

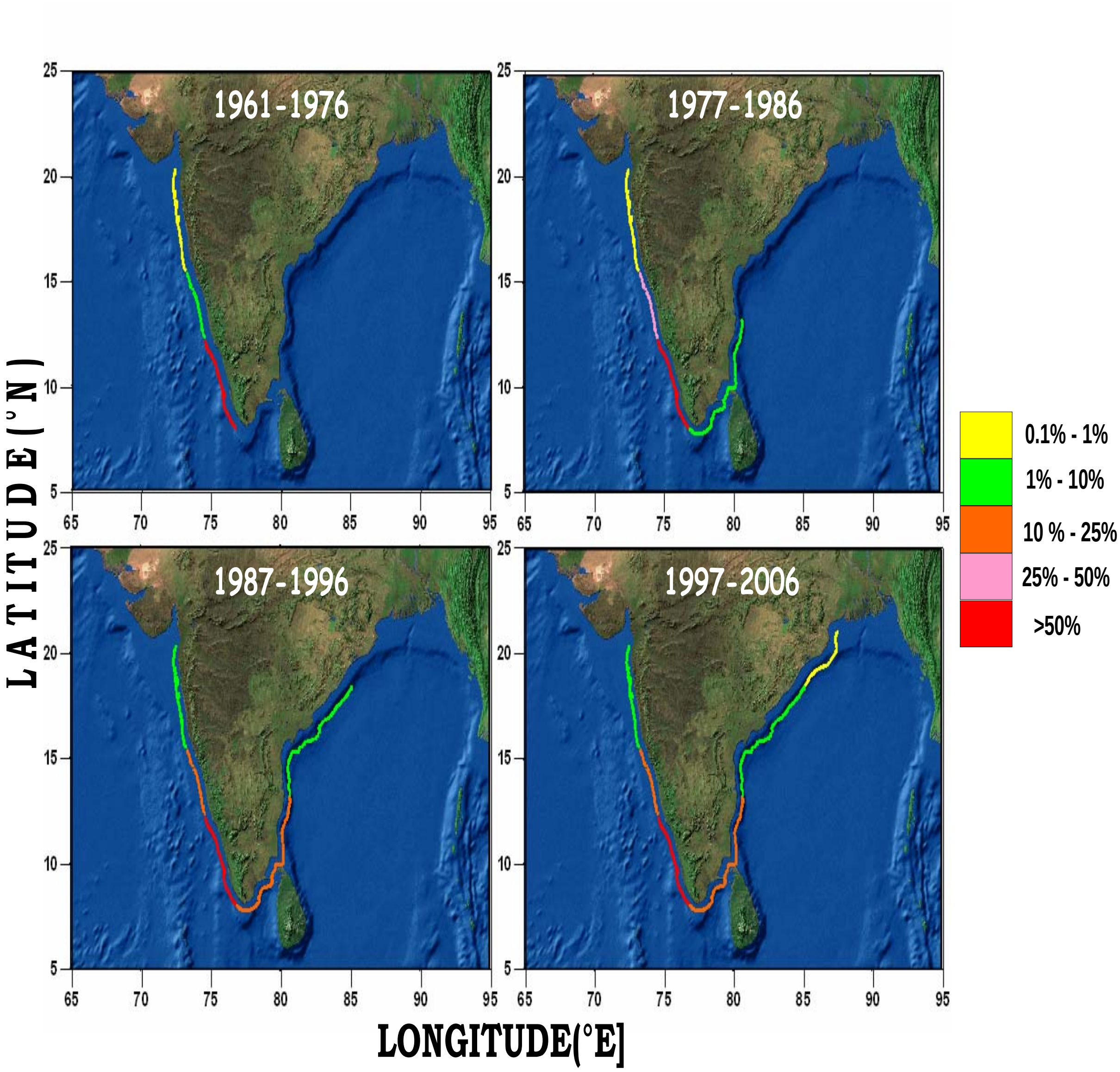



## To identify marine fish species adaptable to climate change

### i. Adaptation by the oil sardine Sardinella longiceps

The oil sardine is a tropical fish species preferring seawater temperature of 28°C or more. It had a restricted distribution along the southwest coast along between 8°N and 12°N. Before 1985, the catch was very low or nil along the east coast. However, from 1985 onwards, the distribution extended along the other coastal regions to the northern latitudes in the Arabian Sea and Bay of Bengal. In 1961-1976, more than 50% of the all India sardine catch was from 8º-11ºN latitude, 25-50% from 11º-15ºN and <1% from 15º-20ºN along the west coast. In 1997-2006, the distributional range has spread, with more than 50% of the all India sardine catch continuing from 8º-11ºN latitude, 10-25% from 11º-15ºN and 1-10% from 15º-20ºN along the west coast; while it is 10-25% from 8-13ºN, 1-10% from 13-19ºN and <1% from 19-21ºN (Fig. 4).

**Fig. 4**. Extension of northern boundary of oil sardine (the percentage in the colour code indicates the percentage contribution of oil sardine catch from each 2° grid to the total oil sardine catch along the entire Indian coast




**ii. Adaptation by the threadfin breams**

It is found that the spawning season of two dominant fish species of threadfin breams *Nemipterus japonicus* and *N.mesoprion* is shifting towards cooler months off Chennai. In 1980 (Fig. 5a), 38% of annual spawning was in the warmer months of April-September (SST: 29-29.5ºC) and 62% in cooler months of October-March (SST: 27.5-28ºC). In 2004, only 5% of annual spawning was in warmer months and the remaining 95% was in cooler months (Fig. 5b).

**Fig5a**

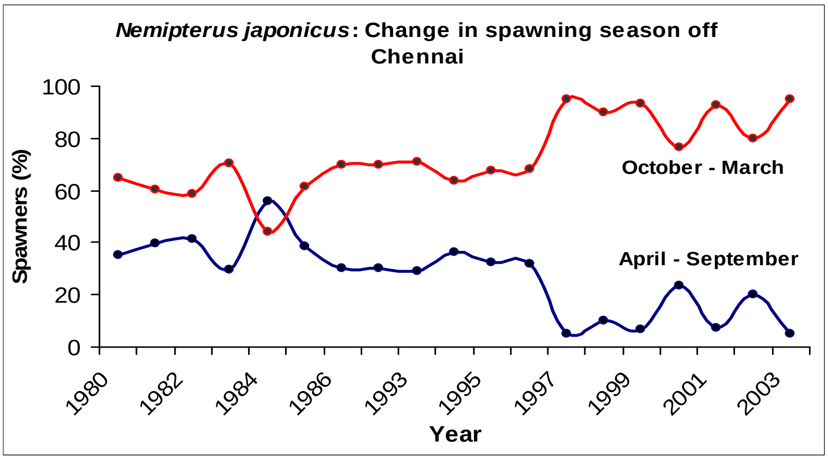
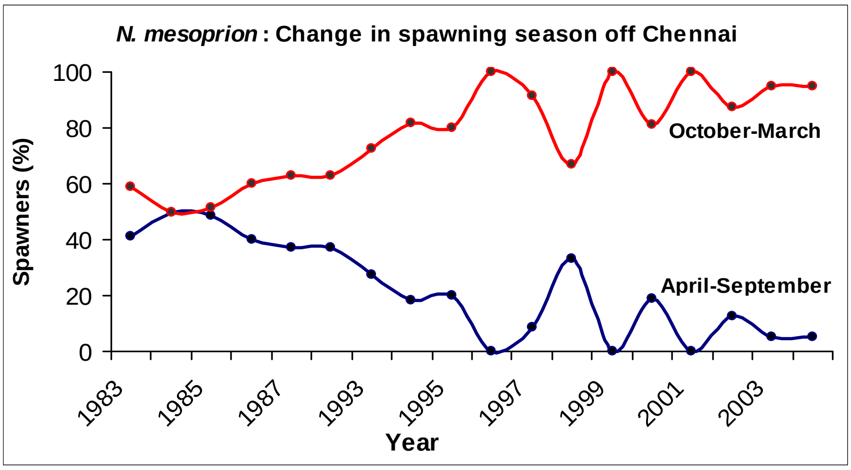



**Fig5b**




**To study the impact of climate changes on sensitive areas such as coral reefs**

Coral bleaching results when the symbiotic zooxanthellae (single-celled algae) are expelled from the host coral organisms due to stress. Bleaching may lead to mortality of corals depending upon the intensity of bleaching. Coral bleaching is caused by stressful environmental conditions such as extreme temperature, low salinity, extreme light and various toxins. However, large scale bleaching episodes are usually associated with unusually high sea temperatures.

Degree Heating Month (DHM) accumulations provide an estimate of the residence time of anomalously warm water in the region and are considered in this study. One DHM is equivalent to 1 month of SST 1°C greater than the expected summer maximum value. Two DHM are equivalent to 2 months of SST 1°C or 1 month of SST 2°C greater than the expected summer maximum value. Bleaching begins for corals exposed to DHM values of 0.5 or more. The following bleaching categories has been recognized in the world oceans based on DHM: Low (0.5-1 DHM); Medium (1-1.5DHM); High (1.5-2.5 DHM); Catastrophic (>2DHM)

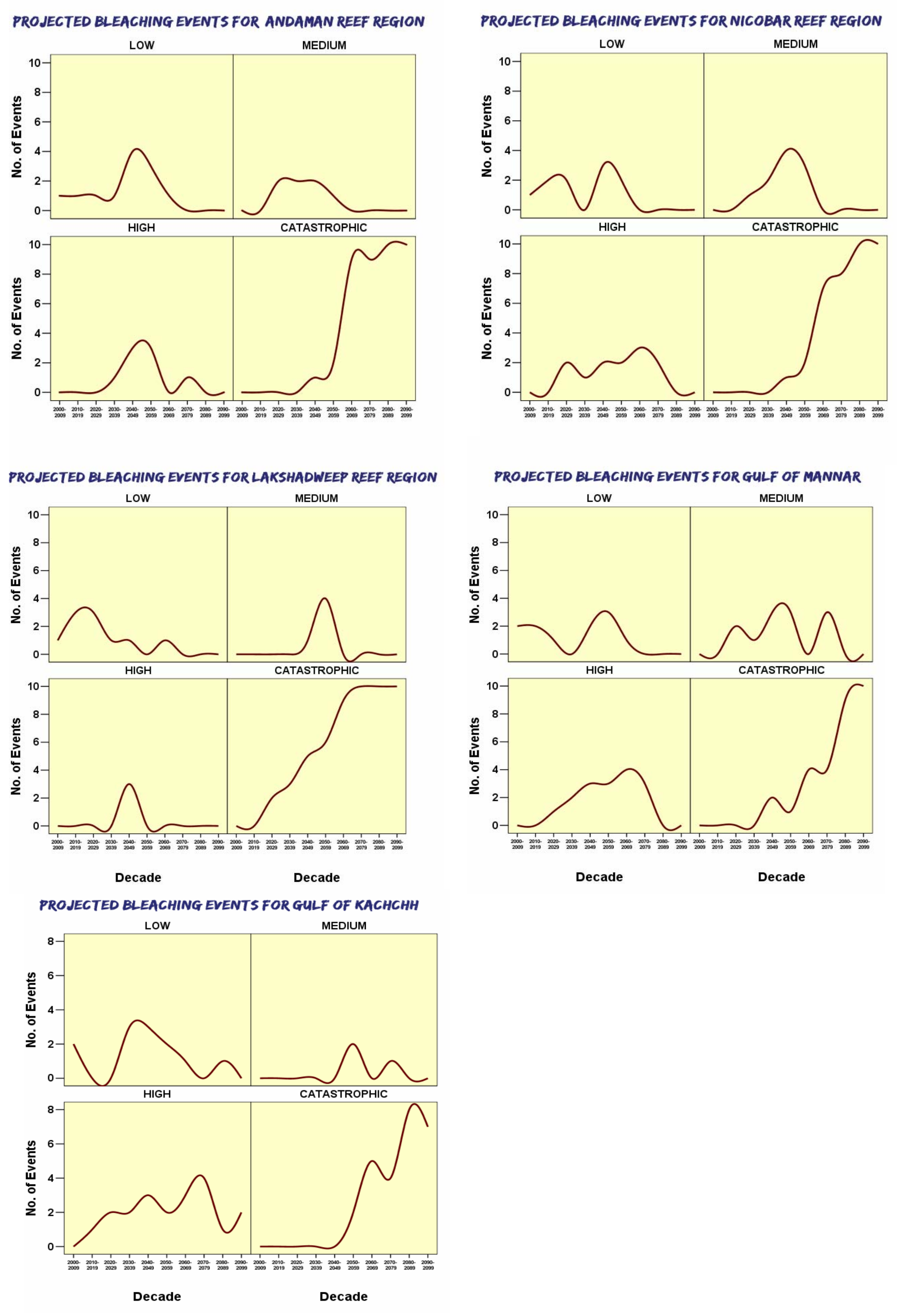
In the present study, DHM was estimated for Andaman, Nicobar, Gulf of Mannar, Lakshadweep and Gulf of Kachchh regions based on 1998 and 2002 bleaching events and coral bleaching was projected for the years 2000 – 2099 (Fig. 6). For this, SST data from UKMO HadCM3 model was applied by using SRES A2 scenario (monthly data for the years 2000-2099).

It is predicted that the coral reefs will begin to decline from the decade 2030-2040, 2020-2030, 2030-2040, 2020-2030 and 2030-2040 in Andaman, Nicobar, Gulf of Mannar, Lakshadweep and Gulf of Kachchh reef regions respectively (Table 2). It is also predicted that the reefs are likely to become remnant in 2050-2060, 2050-2060, 2050-2060, 2030-2040 and 2060-2070 in Andaman Sea, Nicobar Sea, Gulf of Mannar, Lakshadweep Sea and Gulf of Kachchh reef regions respectively.

**Table 2.** Projected bleaching of corals in the Indian Seas

| Location | Decade at which corals begin to decline | Decade at which corals likely to become remnant |
|---|---|---|
| Andaman Sea | 2030-2040 | 2050-2060 |
| Nicobar Sea | 2020-2030 | 2050-2060 |
| Gulf of Mannar | 2030-2040 | 2050-2060 |
| Lakshadweep Sea | 2020-2030 | 2030-2040 |
| Gulf of Kachchh | 2030-2040 | 2060-2070 |

**Figure 6.** Projected bleaching events at Andaman, Nicobar, Gulf of Mannar, Lakshadweep and Gulf of Kachchh during each decade for the period 2000-2099.



**Socio-economic impact on coastal fishing communities**

To understand the socio-economic impact on the coastal fishing communities, stakeholder interviews and survey of ten coastal fishing villages were carried out (Table 3). The selected villages had historic experience of calamities such as cyclone, tsunami etc. Dimension Indices (DI) and vulnerability Indices (VI) were worked out by considering 31 factors under 7 dimensions on a seven-point scale (1-7).

**Table 3.** Villages selected for assessing the impact

| S. No. | Fishing Village | District | State | Historic Experience |
|---|---|---|---|---|
| 1 | Gokarkuda | Ganjam | Orissa | Cy, Re |
| 2 | Uppada | E. Godavari | Andhra Pradesh | Cy, Se,Re |
| 3 | BCV Palem | E. Godavari | Andhra Pradesh | Cy |
| 4 | Jamilabad | Thiruvallur | Tamil Nadu | Cy,Re |
| 5 | Kattupallikuppam | Thiruvallur | Tamil Nadu | Cy,Ts |
| 6 | Karikkattukuppam | Kanchipuram | Tamil Nadu | Cy,Ts,Re |
| 7 | Kovalam | Kanchipuram | Tamil Nadu | Cy, Ts, |
| 8 | Chellanam-South | Ernakulam | Kerala | Ts, Sa, Er |
| 9 | Kumbla-Koipadi | Kasargod | Kerala | Sa, Er |
| 10 | Ullal-Kotepura | Dakshina Kannada | Karnataka | Sa, Se |

Cy: Cyclone, Sa:Sea attack, Ts:Tsunami, Re: Relocated, Er: Erosion, Se:Severe erosion

Among the villages considered (Fig. 7), Gokarkuda in Ganjam district of Orissa was the most vulnerable (VI: 0.53) and BCV Palem in Andhra Pradesh was the least vulnerable (VI: 0.16). Among the dimensions of vulnerability, the demography, food security and habitat induced maximum vulnerability to climate change with average index above 0.50 (Fig. 8).

**Fig. 7.** Vulnerability indices of villages

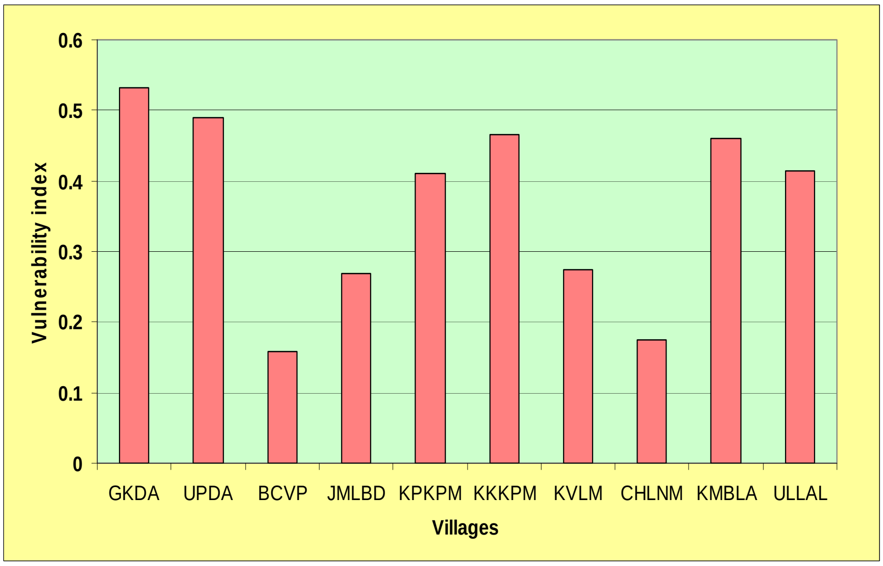
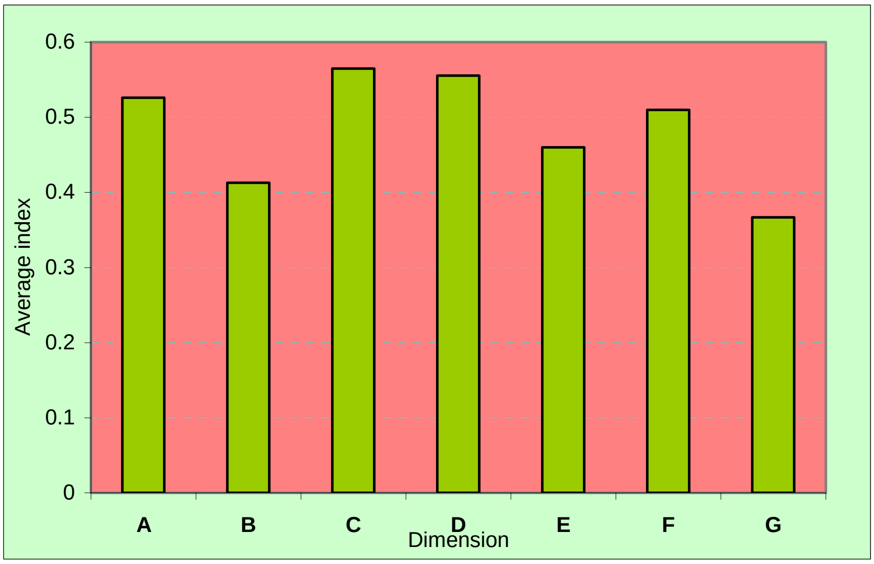


**Fig. 8.** Average index for the dimensions of vulnerability (A : Habitat, B: Infrastructure, C: Demography, D: Food Security, E: Resource Exploitation F: Livelihood and resource base, G: Civic, Health & Community)




## Conclusion

The present study, based on secondary data gathered from different sources, has helped identification of a few adaptable and vulnerable marine species.

To develop robust predictive models and to suggest mitigation measures, collection of primary data and building scenarios are necessary.

Vulnerability indicators developed for a few coastal villages have to be applied on a wider framework with economic implications.

# CENTRAL INLAND FISHRIES RESEARCH INSTITUTE, BARRAKPORE

## 1. Impact of climate change on riverine fishery

Time series data on the various aspects of weather and inland fisheries related to the Ganga river system viz. water temperature, current velocity, rainfall, plankton availability, availability of spawn, fish landings etc. were collected consulting approximately 200 scientific papers, CIFRI Annual Report (1947 to 2004), Reports of Central Pollution Control Board on water quality of Ganga, Handbook in Fisheries Statistics, Govt. of India, different books on Ganga river system etc. The data were analysed statistically and compared with the present data collected through the project. It revealed the following salient aspect:

### 1.1 Biogeographic distribution

#### 1.1.1 Fishes

There is a perceptible shift in biogeographical distribution of the Gangetic fishes. This may be due to rise in maximum temperature in the upper Himalayan stretches of the river Ganga. The cool upper stretch with the earlier maximum average temperature conditions of 17.5ºC was not conducive for these fishes but with the increase of the maximum average temperature in this stretch to 25.5ºC at present, it has become a congenial habitat for the warm water fishes of the lower stretch Fish species like *Puntius ticto, Xenentodon cancila, Mystus vittatus* and *Glossogobius giuris* etc. are now available in the cold water rithron zone of the river Ganga at Haridwar.

Mahseer *Tor putitora* descended during (Dec. 2005- Jan.2006) for the first time upto Karnal where it formed 1.18% to 1.4% the total fish population. The descending run in river Jamuna upto Karnal may have been to avoid low temperature in the upland. The average minimum atmospheric temperature during Dec-Jan 06 ranged from 5.1-8.9°C and max temperature between 17.3-21.4°C .The water temperature being 4.0- 8.5ºC and15.0-20.0ºC respectively around Karnal.

#### 1.1.2 Plankton

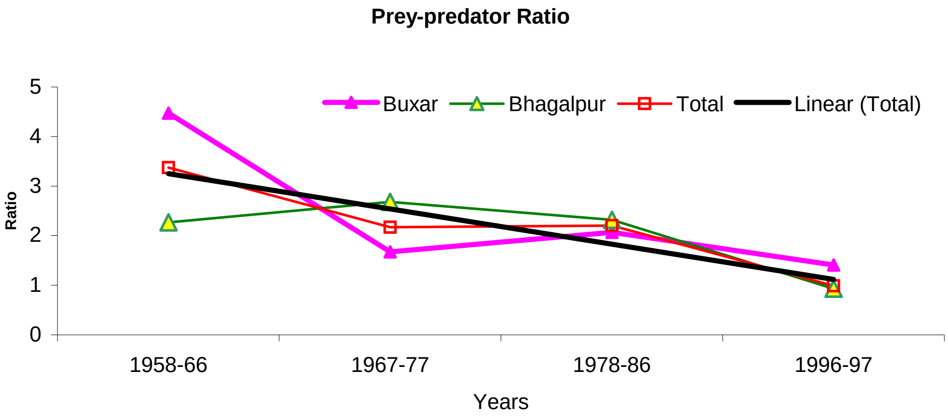
Some genera like *Amphicampus, Tetracycles, Diatoma* and *Ceratoneus* have become insignificant. Temperature is an important environment factors affecting the distributions of these diatoms. *Tetracycles* and *Amphycampus* are usually found in cold mountainous waters, and the genera *Diatoma* and *Ceratoneus* are often encountered in cool temperate waters than in warmer water stretch. During the last decade environmental changes due to rise in water temperature resulted in depletion of these stenothermal phytoplankton genera in river Ganga.

### 1.2 Fish production in river Ganga

The total average fish landing in the Ganga river system declined from 85.21 tones during 1959 to 62.48 tones during 2004.

Clearly any effect of elevated temperature on the top predators will depend on prey availability and prey fish population. One of the more subtle effects of changes in the thermal structure of an aquatic ecosystem is the impact on the prey densities.

Climate warming may produce a large volume of thermal habitat for the fish and if the same number of prey is distributed across this large volume of habitat, prey densities encountered by a predator would be reduced. Reduced prey densities would reduce the predator encounter rate with prey, which would reduce predator consumption rate.



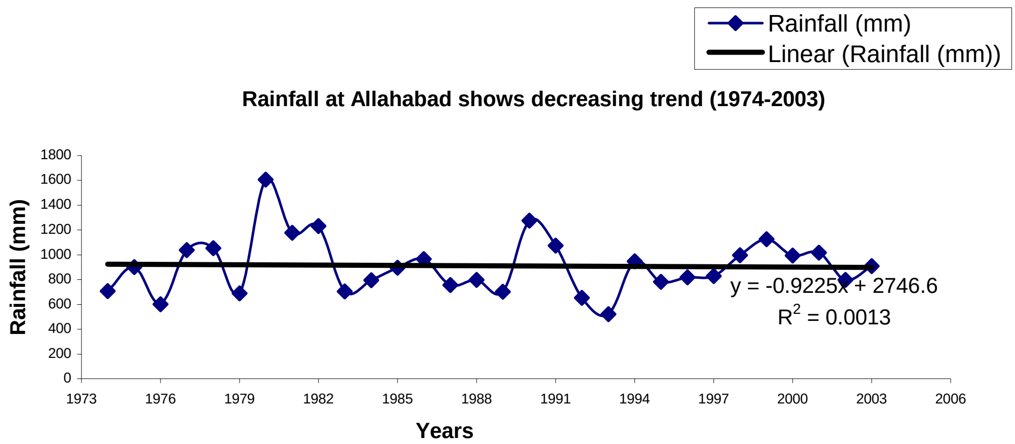

**(Fig. 1)**

Predator (large cat fish) and prey (miscellaneous groups of fish and prawns) ratio in middle stretch (Buxar) and lower stretch (Bhagalpur) has markedly narrow down from 1:4.17 to 1:1.41 and 1:2.27 to 1:0.93 respectively in four decades (1958-1997) period (Fig 1).

## 1.3 Fish recruitment

Fish production in the river Ganga is dependent on the fish recruitment. The fish spawn availability index declined from 2984ml in the 1960s to 27ml in recent years (1994 to 2004). It also showed a continuing deterioration of Indian major carps seed with decreasing percentage of major carp seed (78.62% in 1961-1965 to 34.48% in 2000-04) where as minor carps (from 20.68% in 1961-65 to 52.95% in 1991 to 1995) and other fish seed (from 0.7% in 1961-65 to 47.8% in 2000-04) showed an increasing percentage in the total seed collection.

The failure of recruitment of young ones to the system is because of failure in breeding of the Indian major carps (IMC). Majority of fishes of the Ganga river system breed during the monsoon months. Riverine fishes, by nature are extremely sensitive to change in flood regimes because of their dependence on seasonal floods, which inundate their adjoining areas essentially needed for feeding and reproduction. Decrease in precipitation over the years in the catchment areas of river Ganga, which is more in the plains resulted in decreased runoff (Fig 2). As a consequence the required flow and turbidity of the water essential for breeding of IMC is now not available.




**(Fig 2)**

## 1.4 Sensitivity of Fish landings from river Ganga to Rainfall

The total fish landings from river Ganga at Allahabad showed a decreasing trend during the period of 1974 to 2003 (Fig: 3). The decreasing trend is mainly due to over fishing by increasing the fishing effort in the system. Apart from the regular decreasing trend there are fluctuations in the fish landings from the river depending on recruitment of fish which is influenced by the rainfall, frequency and intensity of flood, current velocity, chemical and hydrobiological characteristics of the river. Therefore quantum of fish landing is also dependent on these climatological factors. An attempt was made to analyse the sensitivity of these fluctuation in fish landings to the total rainfall at Allahabad. It was found that the sensitivity is 0.2588 (Fig 4) which indicates that one millimeter increases or decrease in total rainfall at Allahabad will cause 0.2588 tones increase or decrease in landings.

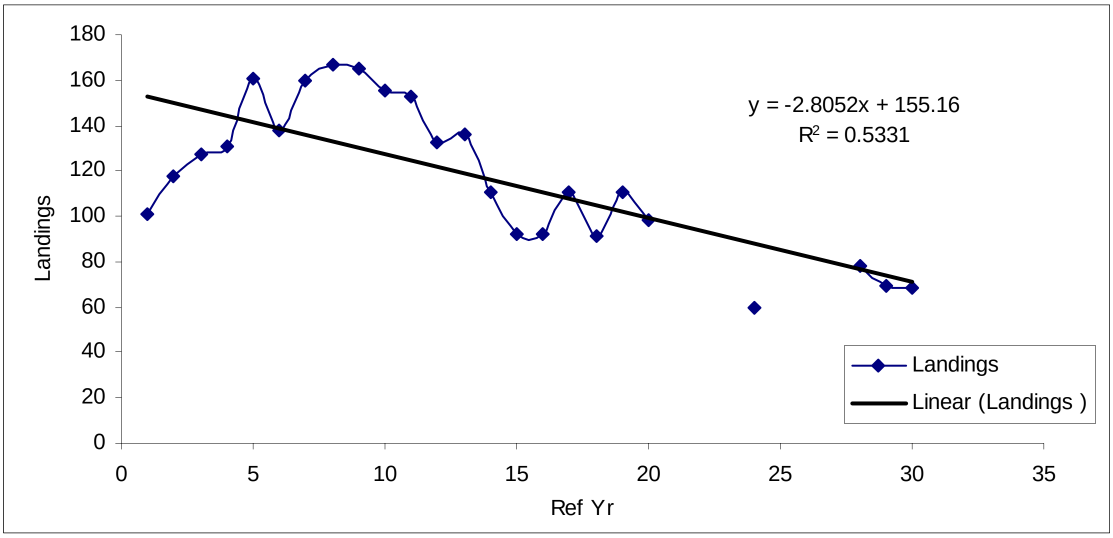



**Fig: 3.** Fish Landings in tones at Allahabad during 1974-2003

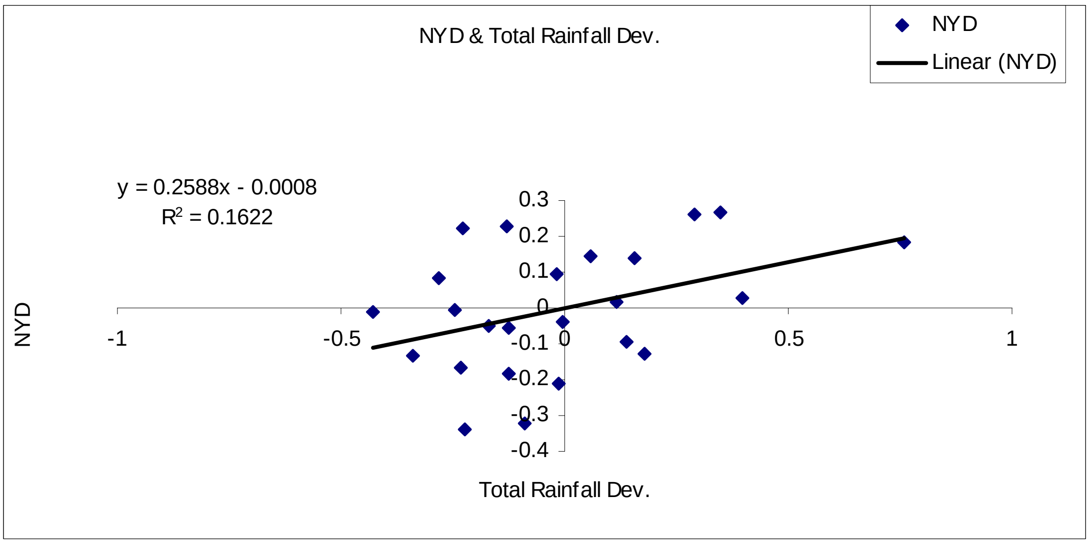



**Fig: 4**. Sensitivity of Fish landings to Rainfall (at Allahabad)

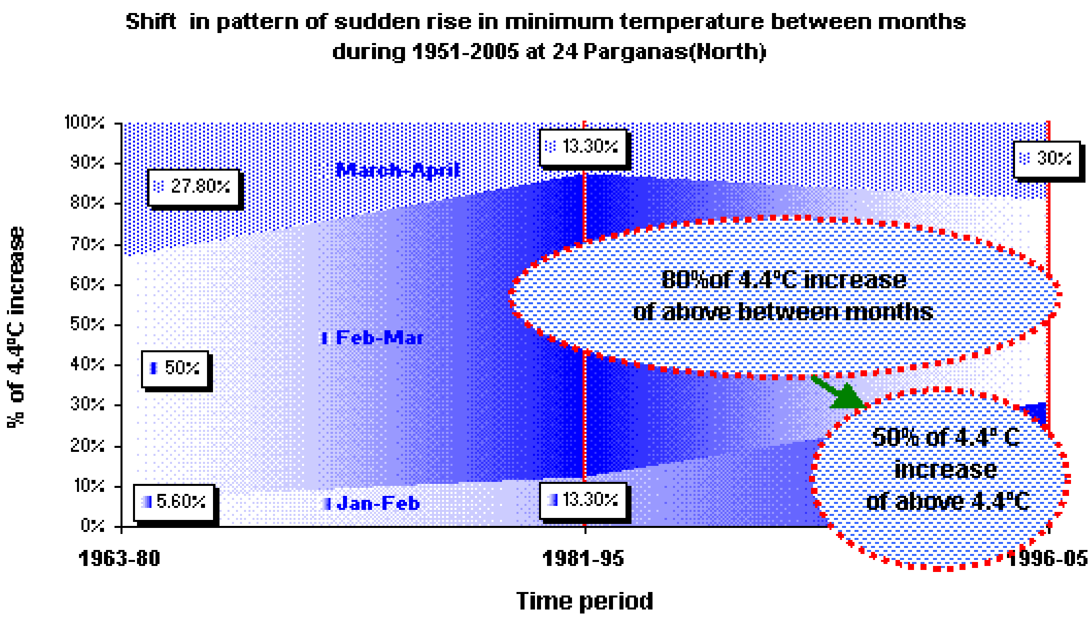
## 2. Impact of climate changes on the physiology of fish

### 2.1 Impact of elevated temperature on the breeding of Indian major carps in West Bengal

Inland aquaculture is centered around the Indian major carps, C. *catla*, *L. rohita* and *C. mrigala*. These fishes are bred in captivity by the technique of hypophysation and their spawning occurs during the monsoon season (June-July) and extends till September. However, in recent years the phenomenon of IMC maturing and spawning as early as March is observed. With this background investigation was conducted to ascertain the impact of elevated temperature on the breeding of Indian major carps and impact on the fishers in the 50 fish hatcheries in four districts viz. North 24 Parganas, Bankura, Burdwan & Hooghly of West Bengal.

#### 2.1.1Trend of temperature alteration in districts:

Indicate that in 24 Parganas (N) the mean maximum air temperature during breeding season in the months of March to September during the time period 1986-2005 has increased by 0.3724ºC where as mean minimum air temperature during the breeding season has increased by 0.6764ºC during the last two decades. In district Bankura the mean minimum air temperature at Bankura during the breeding period in the months March to September shows an increase by 3.8095 ºC in the last two decades (1984-2005). In Burdwan district the mean minimum air temperature during the breeding period shows an increasing trend by 0.1844 ºC where as the mean maximum air temperature has increased by 0.0936 ºC during the last two decades.Analysis of the data of air temperature in the four districts during the time period 1951-1952 to 1996-2005 show the maximum level of increase and occurrence was 4.4ºC between months during the months December to April. This occurrence of 4.4ºC has shown a percentage shift over the years till date. A difference of above 4.4ºC in minimum temperatures between months in different time periods from 1951-52 to as of now 1996-2005 at 24 Parganas (N), Bankura & Burdwan shows a percentage shift. At 24 Parganas (N) there is an increase in the percentage of above 4.4ºC air temperature increase between Jan. –Feb months from 13.3% in 1981-95 to 50% during January-February in 1996-2005 with a distinct shift in increase in air temperature pattern. (Fig.5)




**(Fig. 5)**

Basing on the worked out relation between air and water temperature, the equation $y = 1.1504x - 3.7305$, $R2 = 0.9634$ was put into the recorded air temperature in breeding season months of March-September in the last two decades and the water temperature was arrived at as below.
In the district 24 Parganas (N) both mean maximum and mean minimum air temperature have increased by 0.6764ºC & 0.3724ºC respectively, Basing on the derived relationship of water and air, water temperature is presumed to have increased by 1.668ºC, 0.135ºC respectively.

### 2.1.2 Advancement of breeding period

| Reason | Response % | | | |
|---|---|---|---|---|
| | **24 Parganas (N)** | **Bankura** | **Burdwan** | **Hooghly** |
| *Advancement in breeding period* | | | | |
| Increase in temperature | 95 | 90 | 95 | 90 |
| Improved brooder care | 95 | 85 | 85 | 85 |
| Improved strain of brooders | 45 | 25 | 60 | 50 |
| Better management techniques | 95 | 80 | 90 | 90 |
| Demand & high sell price | 95 | 90 | 90 | 90 |
| Improved breeding technique after training. | 60 | 50 | 70 | 50 |
| *Increase in income* | | | | |
| Improved spawn quality | 70 | 75 | 80 | 75 |
| More quantity spawn | 90 | 90 | 95 | 90 |
| Better marketing | 75 | 60 | 80 | 75 |

During interaction it was noticed that 90-95% indicated temperature rise as the main reason for advancement with 90-95% reasoning to demand & high sell price. The increase in income is attributed to more quantity spawn by 90-95% response. The study also observed that the breeding period of the major carps have advanced in all the districts by 1-2 months since last twenty years. Of all the districts surveyed almost all the fish seed hatcheries claimed that the breeding period have advanced by more than one month. The price per measure (bati) have increased two to three folds in the last decade. The increase in noteworthy in the initial months March-April where the price in almost three times more than during the season ending month of September.

### 2.2 Reproductive competence of fish

Studies were conducted on mature *C. carpio* subjected to enhanced temperature of 34ºC for 21 days. The optimum range of the fish is 15-32ºC and its upper critical range30-41ºC. It spawns optimally in the range of 12-30ºC.

**Mature female *C. carpio* fishes were subjected to an enhanced temperature of 34ºC to study the effect on the reproductive integrity of the fish.**

There has been a decrease in the Gonado somatic index and serum estradiol levels. The cholesterol levels in ovary and liver increased. Histology of the ovary of *C. carpio* exhibited impaired vitellogenesis in oocytes.

There has been an accumulation of liver and ovarian cholesterol (a precursor of steroid hormones) a result the hormone estradiol has depleted (Fig.7). Failure of incorporation of vitellogenin due to increased temperature (which is mainly responsible for increase in gonadal weight) has resulted in lower GSI and estradiol level in serum.

## 2.3 Rapid temperature changes on fish

### 2.3.1 High temperature

In the climate warming scenario fishes will be subjected to the hazard of rapid temperature changes. It is more so in the tropical waters where daily variations in water temperature and thermocline in deep water bodies will assume significance. These effects would often become additive or synergistic with those of other adverse (e.g. low pH, algae, oxygen shortage). It is essential to understand that these temperatures change though sublethal, can place a stress of considerable magnitude on the homeostatic mechanism of fishes at the primary, secondary and tertiary level. Investigation was conducted on the alteration occurring in the levels of various stress sensitive blood and tissue parameters of the fish *L.rohita,* acclimatized at 29°c and subjected to a rapid sublethal rise to 35°c and then maintained at this temperature. The results indicated that the homeostatic mechanism of the fish is stressed. Hypercholesterolemia indicates impaired sterol mechanism. Hyperglycemia and decreased blood sugar regulatory mechanism is evident. The pituitary activation as evidenced by interregnal ascorbic acid depletion and cortisol elevation is pronounced. Oxygen consumption in both the fishes increased as judged by increased haemoglobin. Simultaneously it is observed that compensatory responses were initiated in the fishes within 72 ills. Obviously adaptation to the stress of elevated temperature occurs.

### 2.3.2 Low temperature

To assess the impact of low temperature on fish, experiment was designed where fish *L. rohita* were subjected to gradual lowering of the ambient temperature from 28ºC to 13ºC (critical temperature for *L. rohita*). The result indicated significant rise in plasma cortisol with hyperglycemia. There has been a cessation of feeding and sudden burst of activity followed by a state of total cessation of activity. But death did not occur as the fishes recovered when placed in warmer waters after thirty minutes.

## 2.4 Growth of fish under simulated temperature regime

Normal of 29ºC and three levels of temperature; 4ºC (33ºC), 5ºC (34ºC) and 6ºC (35ºC) above this, were selected for feeding efficiency and growth performance study in fish in relation to increase in ambient temperature. Advance fry of *Labeo rohita* (1.39 ± 0.01291 g.) acclimated in laboratory conditions and adapted to formulated palletised artificial feed

Survivability: Rate of survival of test fishes was 100% in all the thermally treated chambers, which indicated that the thermal range of 29ºC to 35ºC was not fetal for the *Labeo rohita* fingerlings within 13 weeks of exposure.

### 2.4.1 Oxygen consumption

Oxygen consumption in test fishes varied significantly with the change in temperature. At 29 ºC the mean rate of oxygen consumption was 0.0231 mg/g/m. In higher temperature of 33ºC the quantum of oxygen consumption was 25.76ºC % higher and like wise by 33.05% at 34ºC temperature in comparison to 29ºC. With further increase in temperature by 1ºC i.e. at 35ºC there was considerable decline in oxygen consumption as indicated by 19.97% lowering of the value from that of 34ºC.

### 2.4.2 Food consumption

The food consumption of test fishes in terms of percentages of body weight gradually decline with the increase of age and body weight. But the overall food consumption of the fishes increased with the enhancement of ambient temperature with in the experimental range (Fig.1a, b, c & d). The overall food consumption for the fishes at 29 ºC was 15.7718% of the body weight while at 33ºC the value increased to 18.3320%. At 34 ºC the value increased further to 19.7720% and reached to maximum of 20.3010% at 35ºC. Difference in food consumption of fishes was significantly higher at 33 ºC ($P<0.05$) and 34 ºC ($P<0.05$)

compared to 29 ºC. But at 35 ºC the difference in food consumption with that of 29 ºC was not significant at P<0.55 level.

**2.4.3 Growth in fish**

Per day growth in test fishes here expressed in terms of gram per day (g/d) varied within and between the treated temperatures. Fish in 29ºC attained growth @0.434 g/d. At higher temperature of 33ºC the value enhanced by 9.68% (0.476 g/d) and like wise by 27.94% at 34ºC over that of 29ºC. But at 35ºC the rate of growth was arrested to almost that of the fishes exposed to 29ºC temperature. The growth rate (%) of fishes at 33 ºC was significantly (P<0.05) higher compared to 29 ºC. Fishes at 34 ºC attained better growth (P<0.05) than that of 33 ºC.

**2.4.4 Feed conversion ratio (FCR)**

The feed conversion ratio (FCR) for the test fishes under different thermal exposure were calculated from the total weight of the consumed food and the overall gain in fish body weight during the experimental duration. The FCR at 29ºC was 1:1.0087 and the ratio decreased slightly at 33ºC (1:1.0440) but increased to a maximum of 1:0.7045 at 34ºC. The ratio of food conversion was minimum at 35ºC (1:1.1724) indicating the impact of thermal stress on the digestive and assimilation efficiency of the exposed fishes.

**2.4.5 Specific growth rate**

The specific growth rate (SGR) of fishes varied with the change in ambient temperatures. The SGR was maximum at 34ºC (1.91 ± 0.10) temperature in which the food conversion efficiency of the fishes was also at the highest level of 1:0.7055. The SGR increased by 7.9% in 33ºC compared to 29 ºC and further by 17.18% at 34ºC. At 35 ºC the SGR of the fishes decreased by 16.23% of that of 34ºC.

The fishes at the end 92 days exposure showed progressive increase in above mentioned values in the thermal range between 29ºC and 34ºC but the trend reversed with further increased in temperature by 1 ºC to 35ºC. The gain in weight considered as ultimate achievement of all the physiological activities of a living organism and also index for evaluating the physiological efficiency was by 319.16 ± 37.00% of initial in 29ºC. With 4ºC increase in temperature from 29ºC to 33ºC the value raised up by 12.29 % (358.89 ± 33.00 %) and 38.69% (497.75 ± 48.00%) further when the ambient temperature of the fishes was increased to 34ºC. The weight gain in fishes exposed to 35ºC unlike increasing between 29ºC and 34ºC showed decline by 30.10% (347 ± 37.00%) compared to that of 34ºC.

**Table1:** Initial weight, final weight, specific growth rate, weight gain, food conversion ratio and survival% of *L. rohita* fingerlings at four different temperatures (29 ºC, 33 ºC, 34 ºC & 35 ºC)

| | **Different temperature levels** | | | |
|---|---|---|---|---|
| **Parameters** | **29ºC** | **33ºC** | **34ºC** | **35ºC** |
| **Initial wt (grams.)** | $1.36^{a} \pm 0.16$ | $1.40^{b} \pm 0.17$ | $1.39^{b} \pm 0.20$ | $1.43^{c} \pm 0.17$ |
| **Final wt (grams)** | $5.32^{a} \pm 0.36$ | $5.99^{b} \pm 0.28$ | $7.457^{ab} \pm 0.36$ | $5.9^{c} \pm 0.26$ |
| **Specific growth rate (%/day)** | $1.51^{a} \pm 0.11$ | $1.63^{ab} \pm 0.28$ | $1.91^{ab} \pm 0.10$ | $1.60^{c} \pm 0.10$ |
| **Wt.gain %** | $319.61^{a} \pm 37$ | $358.89^{ab} \pm 33$ | $497.75^{ab} \pm 48$ | $347.93^{c} \pm 37$ |
| **FCR** | 1.0087 | 1.044 | 0.7055 | 1.1724 |
| **Survivality%** | 100 | 100 | 100 | 100 |

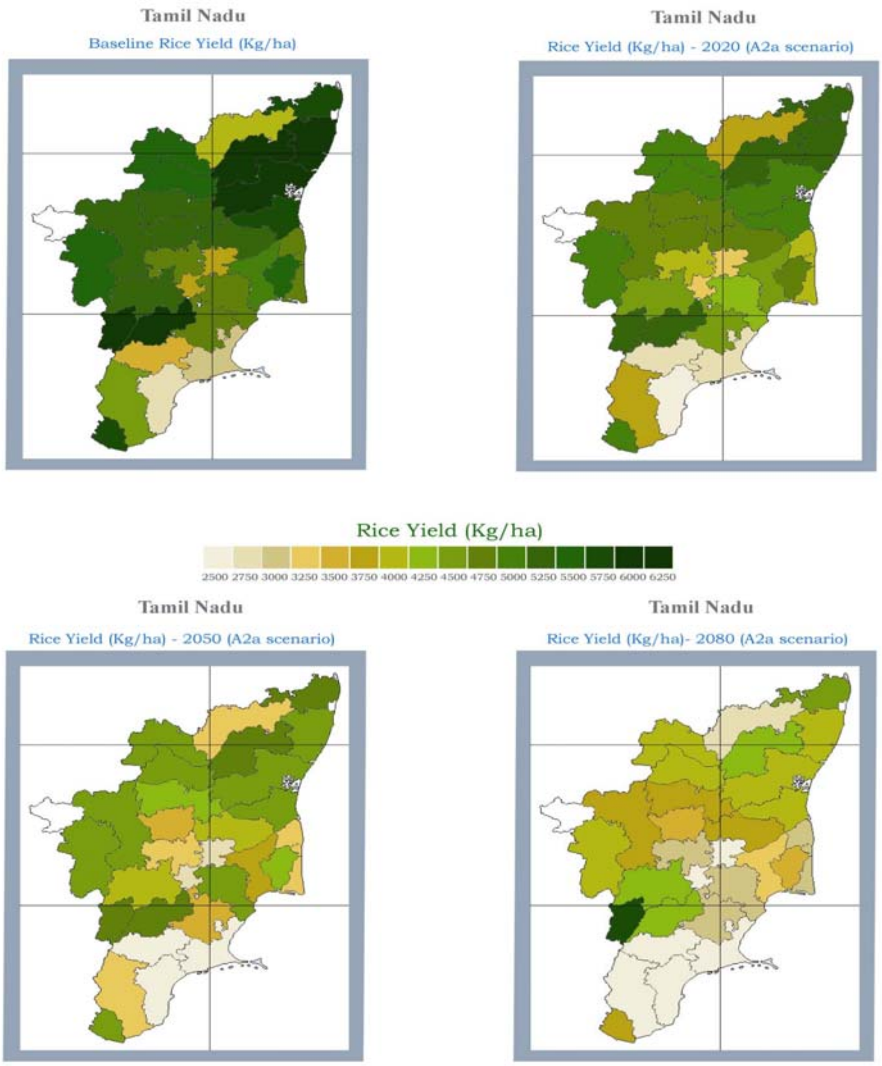
# Tamil Nadu Agricultural University, Coimbatore

## I. Agricultural Meteorology Component

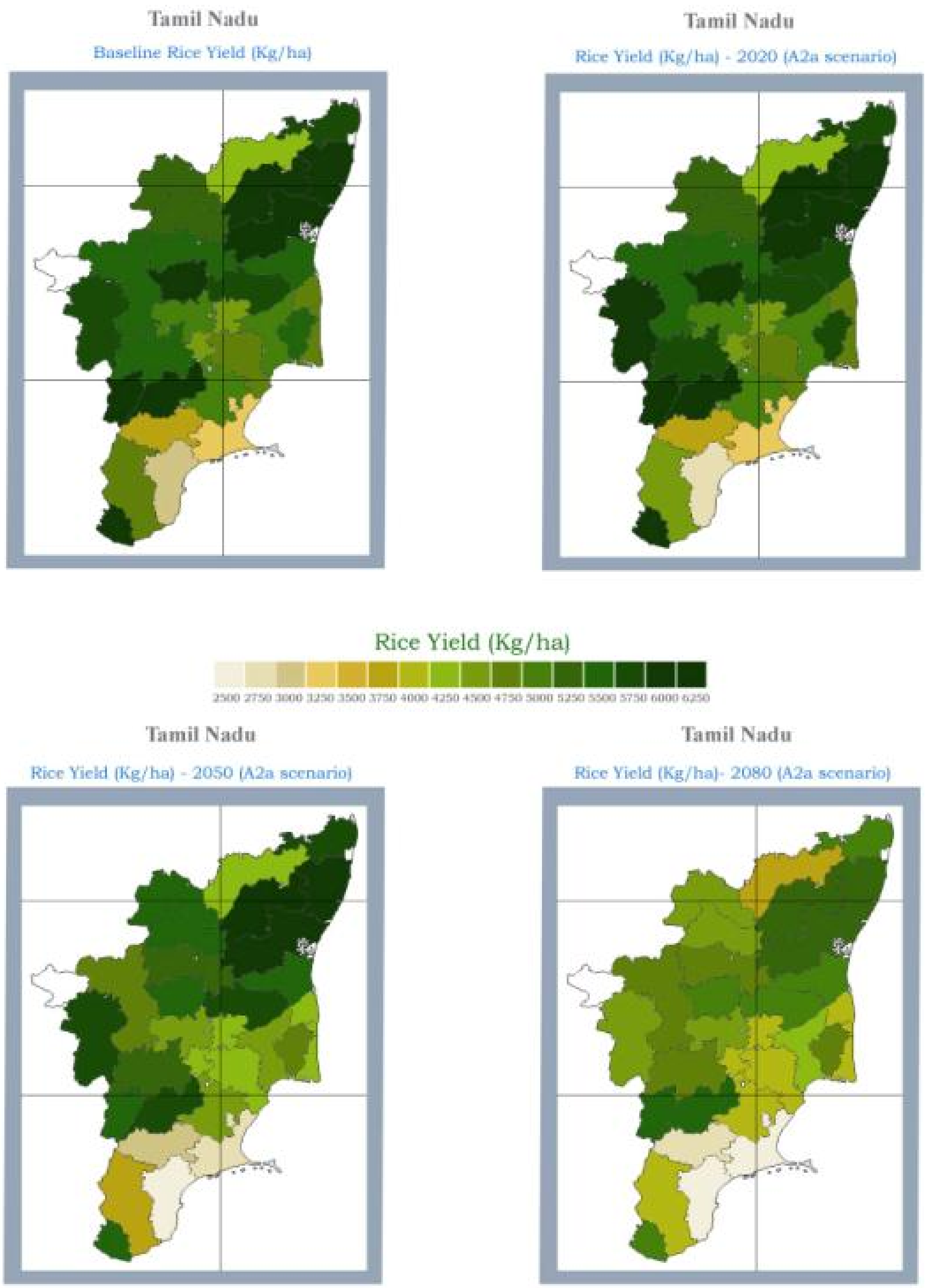
### 1. Impact of Climate Change on Rice Yield of Tamil Nadu

Impact of rice yield on climate change was studied for two rice growing seasons viz., Kharif and Rabi seasons for different districts of Tamil Nadu using INFOCROP model. Standard package of practices and CO43 rice variety which is suitable for all over Tamil Nadu was considered for the study. Only the climate data was changed for different districts and crop weather model was run individually for each district for the base line data. Monthly means of climate change scenario for the year 2020, 2050 and 2080 were then downscaled to daily data and then linked to the base line data for analyzing the changes. The results for Southwest monsoon and Northeast monsoon are presented in Figure 13 and 14 respectively. Expected deviation of rice yield during 2020, 2050 and 2080 over the base year is presented in Figure 15.

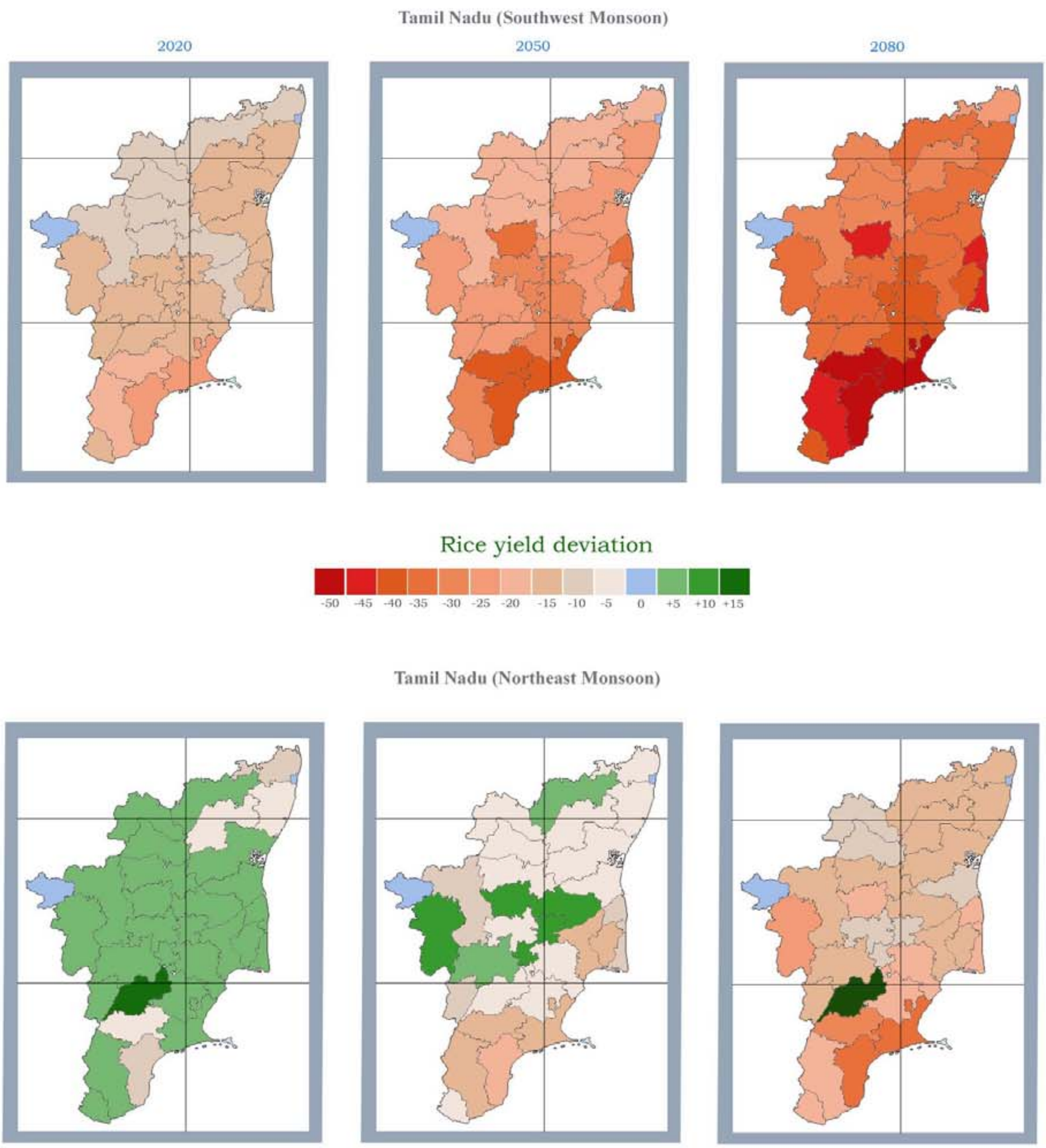
**Figure 13. Impact of climate change on *Kharif* rice yield**



## Figure 14. Impact of climate change on *Rabi* rice yield



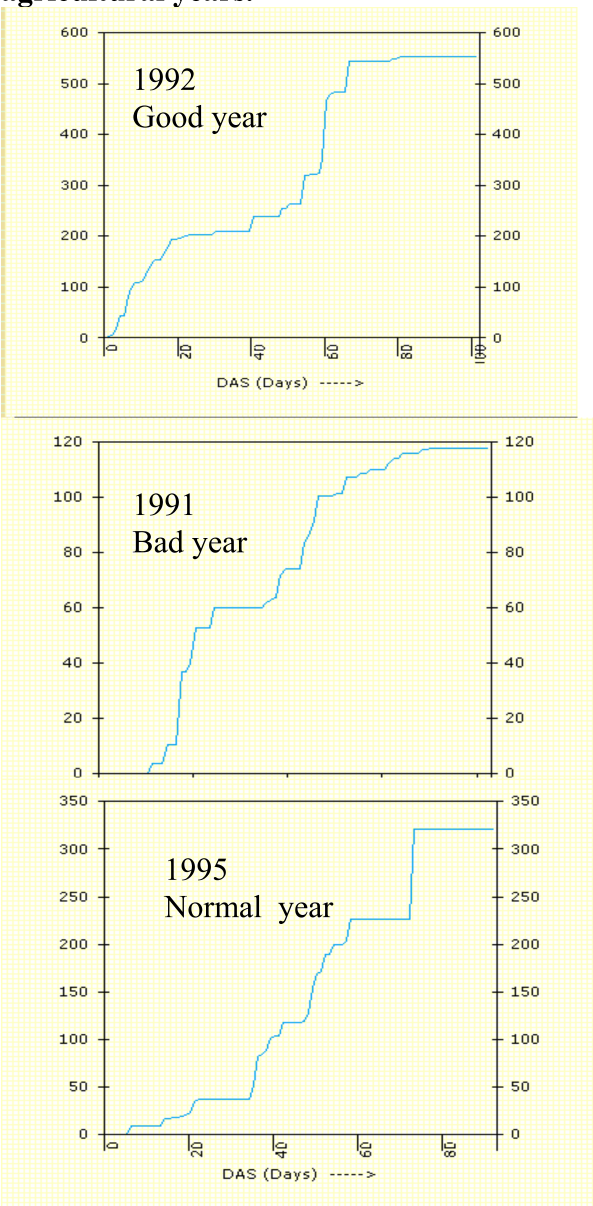
## Figure 15. Deviation of Rice yield due to climate change



**5. Impact of climate change on maize productivity in Coimbatore - a case study**

Impact of climate change on maize productivity in Coimbatore was studied using INFROCROP model. Different climate change scenarios were created and the model was run for three different rainfall situation.

**Fig. 16. Rainfall received during the crop growing period in good, bad and normal agricultural years.**




Weather data of Coimbatore for the year 1992 was used where the rainfall received was 553.2 mm in the crop growing season and was considered as a good year. Year 1991 was considered as a bad agriculture year as the rainfall reacived was only 117.7 mm during the crop growing period. Year 1995 was considered as a normal year wherein 352.8 mm of rainfall was received. The rainfall received during the crop growth period is presented in the Fig.16.

The crop sown on September 17th in all the years. Normally in Coimbatore farmers take up premonsoon sowing on September 17th for the rainfed northeast monsoon crop.

No irrigation was considered and the crop was taken as pure rainfed crop and the model was run for eight different climate change scenarios as listed below

**Climate change scenarios**

1. No climate change
2. Uniform increase in maximum temperature alone by 1degree C
3. Uniform increase in minimum temperature alone by 1degree C
4. Uniform increase in both maximum and minimum temperatures by 1degree C
5. Increase in $CO_2$ level alone to 450 ppm

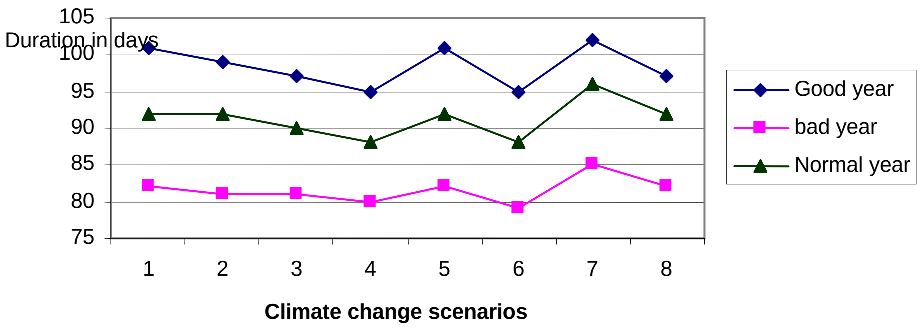
6. Increase in $CO_2$ level to 450 ppm + Uniform increase in both maximum and minimum temperatures by 1degree C
7. Increase in precipitation by 10 %
8. Increase in $CO_2$ level to 450 ppm + Uniform increase in both maximum and minimum temperatures by 1degree C + Increase in precipitation by 10 %

**Results**

**1. Change in crop duration**

Change crop duration for three different agricultural years and for different climate change scenarios are presented in Fig.17.

**Fig.17**. Change in duration of maize crop as influenced by climate change scenarios




In general crop duration was increased in good rainfall years. In bad agricultural years due to very less amount of rainfall the crop ducrion was reduced on an average by 20 days.

Among the climate change scenarios, increase in temperature reduced the crop duration. The magnitude of reduction was more during good agricultural year. Increase in night temperature had more impact on reducing the duration of the crop. The effect minimum temperature was almost double as that of the maximum temperature. When both maximum and minimum temperatures were increased by 1 degree, then the crop duration was reduced by as much as 6 days in good years and 4 days in bad and normal years.

Increase in $CO_2$ alone did not influence the duration of the crop. But together with temperature, it reduced the crop growing period. Increasing the rainfall by 10 % increased the duration of the crop especially in bad and normal rainfall years by 4 days.

**2. Days to Anthesis**

Data on days to anthesis is given in the table. Only minimum temperature had reduced the days to anthesis and the reduction was just by one day.

**Table 4. Days to Anthesis**

| | Good year | | Bad year | | Normal year | |
|---|---|---|---|---|---|---|
| **Scenario** | **Days** | **% deviation** | **Days** | **% deviation** | **Days** | **% deviation** |
| T1 | 55 | 0.0 | 54 | 0.0 | 50 | 0.0 |
| T2 | 56 | 1.8 | 54 | 0.0 | 51 | 2.0 |
| T3 | 54 | -1.8 | 53 | -1.9 | 50 | 0.0 |
| T4 | 54 | -1.8 | 53 | -1.9 | 50 | 0.0 |
| T5 | 55 | 0.0 | 54 | 0.0 | 50 | 0.0 |
| T6 | 54 | -1.8 | 52 | -3.7 | 50 | 0.0 |
| T7 | 56 | 1.8 | 55 | 1.9 | 53 | 6.0 |
| T8 | 55 | 0.0 | 54 | 0.0 | 53 | 6.0 |

### 3. Mean Crop growth

**Table 5. Mean crop growth rate (CGR) in kg/ha/day**

| | Good year | | Bad year | | Normal year | |
|---|---|---|---|---|---|---|
| **Scenario** | **CGR** | **% deviation** | **CGR** | **% deviation** | **CGR** | **% deviation** |
| T1 | 186.8 | 0.0 | 3.5 | 0.0 | 131.9 | 0.0 |
| T2 | 162.1 | -13.2 | 3.1 | -11.9 | 136.1 | 3.2 |
| T3 | 143.9 | -23.0 | 4.6 | 28.5 | 121.6 | -7.8 |
| T4 | 129.0 | -30.9 | 4.0 | 12.4 | 105.7 | -19.9 |
| T5 | 185.6 | -0.6 | 3.7 | 3.1 | 137.5 | 4.2 |
| T6 | 124.8 | -33.2 | 3.9 | 9.6 | 109.9 | -16.7 |
| T7 | 221.7 | 18.7 | 4.3 | 21.8 | 222.0 | 68.3 |
| T8 | 154.8 | -17.1 | 6.3 | 76.6 | 201.2 | 52.5 |

Drought conditions reduced the crop growth to a greater extent. Increase in maximum temperature resulted in reduction in crop growth rate by 1302 and 11.9 per cent in good and bad years. But increase in minimum temperature had differential impact in good and bad rainfall years. Under good rainfall years increase in night temperature had resulted in reduction of crop growth rate by 23 per cent and in contrast to that increase in night temperature had increased the crop growth rate by 28.4 per cent in bad years. Increasing $CO_2$ concentration to 450 ppm had beneficial effect on crop growth rate under normal and bad rainfall years but had no impact on good rainfall years.

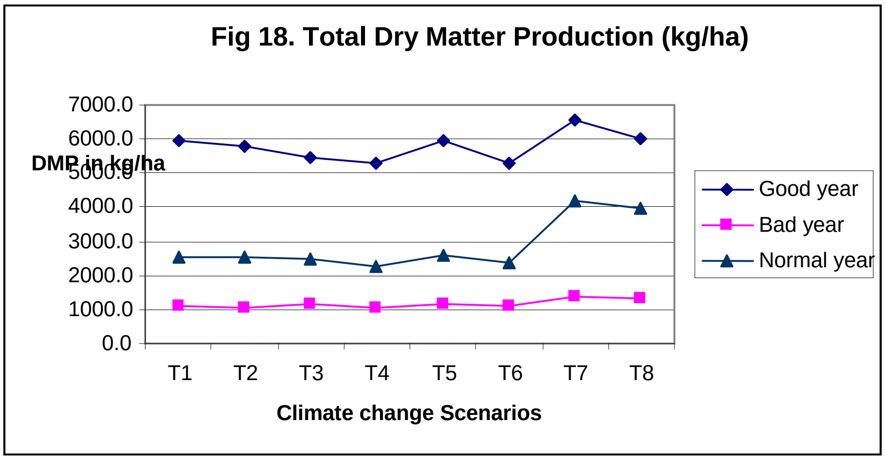
Increase in rainfall by 10 % had increased the CGR in all the cases. Combined effect of increase in precipitation, temperatures and $CO_2$ concentration had positive impact during bad and normal rainfall years but had negative impact on good rainfall years.

### 3. Total Dry Matter Production (Kg/ha)

Result on total dry matter for different climate change scenarios and for different rainfall years are presented below.

**Table 6. Total Dry Matter Production (DMP) in Kg / ha**

| | Good year | | Bad year | | Normal year | |
|---|---|---|---|---|---|---|
| **Scenarios** | **DMP** | **% deviation** | **DMP** | **% deviation** | **DMP** | **% deviation** |
| T1 | 5937.4 | 0.0 | 1116.8 | 0.0 | 2526.7 | 0.0 |
| T2 | 5787.8 | -2.5 | 1034.6 | -7.4 | 2552.5 | 1.0 |
| T3 | 5460.2 | -8.0 | 1146.2 | 2.6 | 2491.2 | -1.4 |
| T4 | 5304.1 | -10.7 | 1054.3 | -5.6 | 2282.7 | -9.7 |
| T5 | 5946.4 | 0.2 | 1142.2 | 2.3 | 2612.2 | 3.4 |
| T6 | 5302.4 | -10.7 | 1078.1 | -3.5 | 2356.2 | -6.7 |
| T7 | 6573.9 | 10.7 | 1388.1 | 24.3 | 4201.0 | 66.3 |
| T8 | 6008.1 | 1.2 | 1329.5 | 19.0 | 3983.8 | 57.7 |




Total dry matter production was not affected much by climate change scenarios in bad rainfall years except that increasing rainfall amount by 10 per cent increased the dry matter production by 24 per cent. In normal and good rainfall years, increase in temperature reduced the dry matter production. But together with increase in rainfall and $CO_2$ level, total dry matter production also got increased.

### 3. Economic Yield (Kg/ha)

**Table 7. Economic yield in Kg / ha**

| | Good year | | Bad year | | Normal year | |
|---|---|---|---|---|---|---|
| **Scenarios** | **DMP** | **% deviation** | **DMP** | **% deviation** | **DMP** | **% deviation** |
| T1 | 2132 | 0 | 267.5 | 0 | 601 | 0 |
| T2 | 2265.1 | 6.2 | 236.3 | -11.7 | 581.8 | -3.2 |
| T3 | 2189.4 | 2.7 | 290.5 | 8.6 | 673.8 | 12.1 |
| T4 | 2192.2 | 2.8 | 254.2 | -5.0 | 652.3 | 8.5 |
| T5 | 2144.9 | 0.6 | 275.2 | 2.9 | 618.6 | 2.9 |
| T6 | 2215.8 | 3.9 | 268.8 | 0.5 | 671.5 | 11.7 |
| T7 | 2367.2 | 11.0 | 376.3 | 40.7 | 1026.5 | 70.8 |
| T8 | 2528.8 | 18.6 | 359.2 | 34.3 | 1143.5 | 90.3 |

Data on economic yield is presented in the following table. Analysis of the data indicates that the expected change is climate is going to benefit maize crop production in Coimbatore area. Maximum increase could be noticed for the increase in rainfall by 10 per cent and for the combined increase of temperature rainfall and $CO_2$ levels.
Though this particular case study indicates the beneficial effect of expected climate change, we can not come to any solid conclusion as it is a single location data for a specific case. Hence in depth analysis need to be undertaken for deriving valid conclusion.

### Conclusions

Different regions of Tamil Nadu exhibit diverse changes over the next century. During Southwest monsoon, rainfall is expected to increase in the southern parts of Tamil Nadu, while it is expected to decrease in the central regions and remains the same in the northern parts of Tamil Nadu. During Northeast monsoon only in the central parts of Tamil Nadu, rainfall is expected to decrease and in southern and Northern parts not much change is expected.

As far as temperature is concerned both maximum and minimum temperatures are expected to rise by 2 to 5 degree Celsius. Warming expected more in the central and north eastern parts of Tamil Nadu.

Chance in climate is expected to create both positive as well as negative impact on rice yield of Tamil Nadu. Impact is more during Kharif season (South west Monsoon) than in Rabi (Northeast monsoon) season. During Kharif season in 2020, 10 to 15 per cent reduction in rice yield is expected due to increase in temperature and change in rainfall. In 2050, 30 to 35 % yield reduction and in 2080, upto 80 % yield reduction is expected. Though, the reduction is found in all most all the districts, it is more pronounced in the major rice growing districts such as Thanjavur and Nagapattinam.

In contrast to this, during Northeast monsoon, there is increase in rice yield uo 10 10 % due to change in climate was noticed. This might be due to the positive effect of slight increase in temperature during the rabi season, where the crop suffers due to low air and water temperatures at present. As the major rainy season and the winter season of Tamil Nadu fall in the rabi season, most of the time the water temperatures are lower. Increase of 1 to 2 degree Celsius temperature must have created a positive impact during 2020.

In 2050, rabi rice yields are almost same as that of the current productivity and further increase in temperature during 2080 had negative impact and reduced the yields upto 25 % in most of the districts of Tamil Nadu.

**Future challenges**

- Keeping in mind the increase in population, the food grain requirement and the impact of change in productivity due to climate change, management options should be tailored to increase the yield of important crops even under changing climate scenarios.
- Though, many model projections on future climate change scenarios are available, more precise scenarios with finer spatial dimension is required to asses the impacts.
- Vulnerable regions for climate change should be identified.
- More studies need to be done for other major food crops and commercial crops.
- Climate change mitigation strategies need to be developed

**II. Soil Science Component**

Two locations were selected in Agro-ecological sub region (AESR) 18.2 of India (Fig.19). The study area comprises of a cluster of fifteen coastal villages from two taluks of Nagapattinam district (Table 8 and Fig. 20) and a cluster of thirteen coastal villages from two taluks of Cuddalore district (Table 9 and Fig. 21).

Nagapattinam part of the study area extend from 10.5756 º to 10.8254 º N latitudes and 79.7834 º to 79.8587 º E longitudes. The total area of the fifteen villages selected in Nagapattinam district is 103.60 sq. Km. Cuddalore part of the study area extend from 11.4365 º to 11.6644 º N latitudes and 79.6919 º to 79.7785 º E longitudes. The total area of the thirteen villages selected in Cuddalore district is 78.76 sq. Km. All the twenty eight villages selected for the present investigation constitute 182.36 sq.Km of coastal region.

**Table 8. List of villages selected for the study in Nagapattinam district and the areal extend**

| S.No. | Village Name | Area in Sq.Km |
|---|---|---|
| | **Nagapattinam taluk** | |
| 1. | Andanampettai | 2.21 |
| 2. | Aivanallur | 3.54 |
| 3. | Velanganni | 4.01 |
| 4. | Chinna Tumbur | 8.37 |
| 5. | Karuvelankadai | 3.04 |

| | | |
|---|---|---|
| 6. | Papakoil | 5.83 |
| 7. | Therkkupoyyur | 6.61 |
| 8. | Vadavur | 4.04 |
| 9. | Vadakkupoyyur | 10.97 |
| | **Keelvelur taluk** | |
| 10. | Talayamalai | 3.96 |
| 11. | Tirupoondi Kilsethi | 9.36 |
| 12. | Tirupoondi Melsethi | 7.59 |
| 13. | Pratabaramapuram | 15.44 |
| 14. | Karapidagai | 8.91 |
| 15. | Vilundamavadi | 9.70 |
| | Total | 103.60 |

**Table 9. List of villages selected for the study in Cuddalore district and the areal extend**

| S.No. | Village Name | Area in Sq.Km |
|---|---|---|
| | **Cuddalore taluk** | |
| 1. | Thiruchopuram | 5.28 |
| 2. | Allapakkam | 1.29 |
| 3. | Kayalpattu | 7.90 |
| 4. | Kambalimedu | 2.82 |
| 5. | Andarmullipallam | 7.64 |
| | **Chidambaram taluk** | |
| 6. | Periyapattu | 7.39 |
| 7. | Villianallur | 8.16 |
| 8. | Silambimangalam | 7.10 |
| 9. | Ariyagosthi | 8.80 |
| 10. | Kothattai | 7.50 |
| 11. | Chinnakummati | 5.06 |
| 12. | Parangipettai | 3.48 |
| 13. | Agaram | 6.34 |
| | Total | 78.76 |

**Salinization of lowland rivers, surface waters and aquifers**

Rising relative sea level will progressively affect the quality of freshwater resources in coastal wetlands, lowland river reaches, aquifers and soils by salinisation (more saltiness from incursion of rivers or seepage of seawater). Soils in low-lying agricultural areas may be affected by sporadic overtopping and flooding of saltwater, with effects being cumulative.

Coastal aquifers normally flow toward adjacent surface waters, such as estuaries or the sea. Aquifers with low hydraulic heads, could, however, be induced to flow in the reverse direction with a rise in sea level under excessive pumping rates for municipal water supply. Increasing salinisation of peripheral lands around estuaries will have effects on their flora and fauna, being part of a gradual process that will eventually transform 'land' into salt meadows, then salt marshes, and finally into the estuary proper, provided there are no artificial constraints like bunds or stop-banks.

In the coastal regions of Tamil Nadu, salinity of groundwater due to the intrusion of seawater into the subsurface aquifer is a major problem. Due to excess withdrawal of groundwater, the water table has fallen too far below thereby allowing seawater to percolate.

**Digitization of village maps**

Village boundaries were extracted from taluk maps and digitized using digitizer board with the help of CartaLinx Spatial Data Builder software. The digitized map was registered with a georeferenced GIS map of districts of Tamil Nadu state. For the study area, field boundaries were digitized from village maps and registered with the village boundary map.

**Soil resource of the study area**

Soil resources of the villages of Nagapattinam and Cuddalore part of the study area was mapped (Fig 22a & 22b) using IRS 1D PAN + LISS3 merged satellite data. The FCC was visually interpreted based on the interpretation keys developed from image elements namely tone, texture, size, shape and mottle through onscreen digitizing. Different image interpretation units (IIUs) for the study area were demarcated. On the basis of prefield image interpretation, sample areas covering all mapping units were selected in the form of sample strips of suitable size for ground truth collection, profile studies and field traversing. Horizon-wise soil samples were collected from the representative pedons and analyzed for physical, chemical and nutrient parameters. The soils of the study area were classified based on the morphological, physical, chemical and exchangeable properties of soils and climatic data (soil moisture and temperature regimes) following the Keys to Soil Taxonomy. The final soil map was prepared by transferring the boundaries of IIUs to the base map of 1:25,000 scale and enlarged to 1:5,000 scale village maps. A legend for the mapping unit showing the map symbol, phases of soil series/soil association and extend of mapping units was prepared and incorporated in the soil map (Fig. 22a & 22b). Mapping unit shows the phases of soil series /soil series association (Tables 10a & 10b). Soil properties are presented in Tables 11 (a-c) and 12 (a-c).

The texture of the soils of Nagapattinam part of the study area ranged from sand to silty clay. The structure ranged from single grain to subangular blocky. Concretions of Fe-Mn were observed in Kilsethi, Melsethi and Paravai series. Slickensides and cracks were found in Kivalur and Paravai series. Soil reaction varied over a range of 6.82 to 8.52 and the EC was in the range of 0.01 to 8.54 $dS^{-1}$ Sodium was found to be the predominant cation in all the soil series. The dominant anion was Cl followed by bicarbonate and sulphate in Vludalakudi mild alkaline phase, Kilsethi, Melsethi, Nagapattinam and Paravai series. Organic carbon content was very low in all the soil series. All the soil series registered low available N and K and the availability of P was medium to high.

The texture of the soils of Cuddalore part of the study area ranged from sand to clay. The structure ranged from single grain to subangular blocky. Slickensides and cracks were found in Kondal series. Soil reaction varied over a range of 6.58 to 9.15 and the EC was in the range of 0.02 to 22.71 $dS^{-1}$ Calcium and magnesium were found to be the predominant cation in all the soil series. The dominant anion was Cl followed by bicarbonate in Vandiyampalayam, Padugai, Mangadu, Parankipettai and Kondal series. Organic carbon content was low in all the soil series.

**Land use and Land cover map**

The land use and land cover data were collected from the revenue records of the respective village administrative office, during the period April, 2004. Database on land use/land cover were developed using Microsoft Excel Package. Then the database was exported to manpinfo via dBase IV format and the attribute table was geocoded using survey number as the key field. By database query analysis, thematic maps on land use were generated (Fig 23a & 23b). During ground truth collection the landuse data were validated and the land use composition was collected for the level I, level II and level III of the land use / land cover classification (NRSA, 1990). The major land use was agriculture (Table 13a, b and 14a, b).

**Extend of area prone to sea water intrusion**

Digital elevation model for the Nagapattinam part of the study area was downloaded from

NASA site. The data is generated from SRTM (Shuttle Radar Topographic Mission) and the spatial resolution is 90m with elevation values rounded to nearest meter. The data is used to model the intrusion of sea water as a result of dike failure. If a dike fails, inundation will occur in the areas that have an elevation lower than the outside water level and that are connected with the location of the dike failure. Simply slicing the DEM up to a certain flood level will not show the actual flooded area. In order to find the topographically connected areas a topographic operator (ie., Grouping function of IDRISI package) was used in conjunction with a connectivity operator. Since the starting cell of dike failure at different location was less than or equal to 2 m elevation from the mean sea level, two flood maps were created: one for a water level of 3 m and one for a water level of 4 m. The area of inundation and volume of water were estimated for the three flood levels from the corresponding raster cells. The submergence of land due to sea water rise under three different scenarios were modeled for Nagapattinam region (Fig. 24a, b & c).

It was inferred that at a water level rise of 2.0 m, 10.49 per cent (1084.12 ha) of the area will be flooded. At 3.0 m 24.56 per cent (2549.74 ha) and at 4.0 m 29.64 per cent (3076.58 ha) of the study area was found to be inundated. The calculated volume of flood water for water level rise of 2.0, 3.0 and 4.0 m was 2168.24, 7649.22 and 12306.32 ha m, respectively. Number of fields affected by different levels of sea level rise was found to be 565, 1502 and 1803 under the scenarios of 2m, 3m and 4m rise in sea level respectively.

Similar analysis was done for the Cuddalore part of the study area. The extend of land that will be submerged under different scenarios of sea water rise in Cuddalore part was very less when compared to the corresponding situation in Nagapattinam part (Fig. 25a, b & c). The estimated area liable to flood was 25.41 ha at 2 m sea level rise; 66.91 ha at 3 m sea level rise and 876.56 ha at 4 meter sea level rise. The estimated volume of flood water at water level 2, 3 and 4 m were 31.34, 162.91 and 2401.86 ha m, respectively.

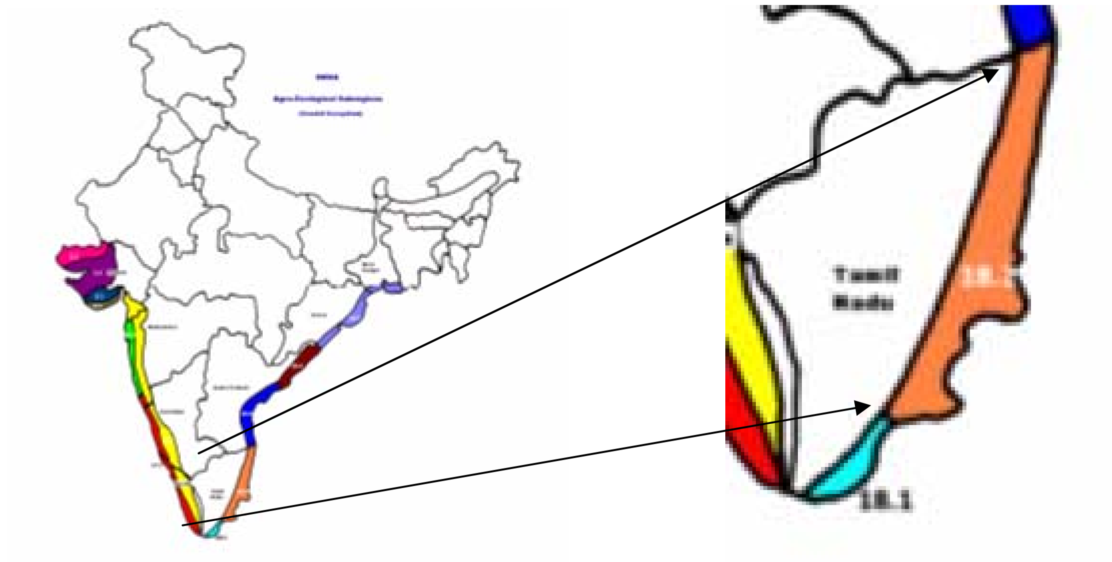



**Figure 19. Agroecological sub-regions of coastal ecosystem of India and AESR 18.2 selected for the present investigation**

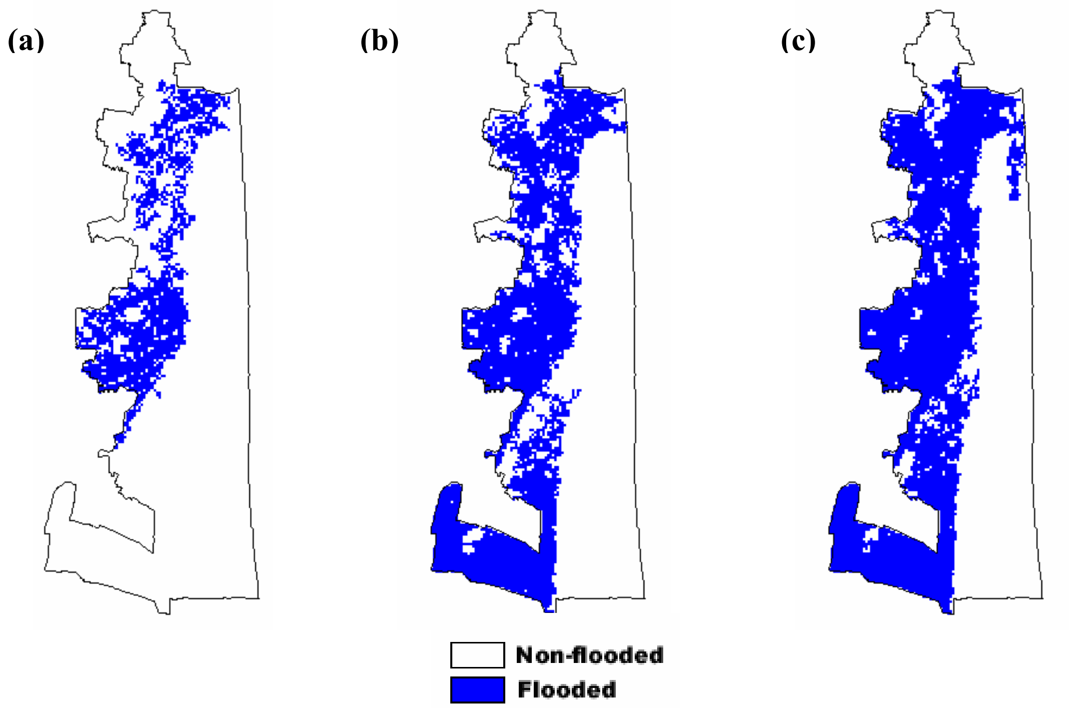



**Figure 24. Estimated area flooded, using a DEM for Nagapattinam part of the study area (a) Flood level of 2.0 m (b) Flood level of 3.0 m (c) Flood level of 4.0 m**

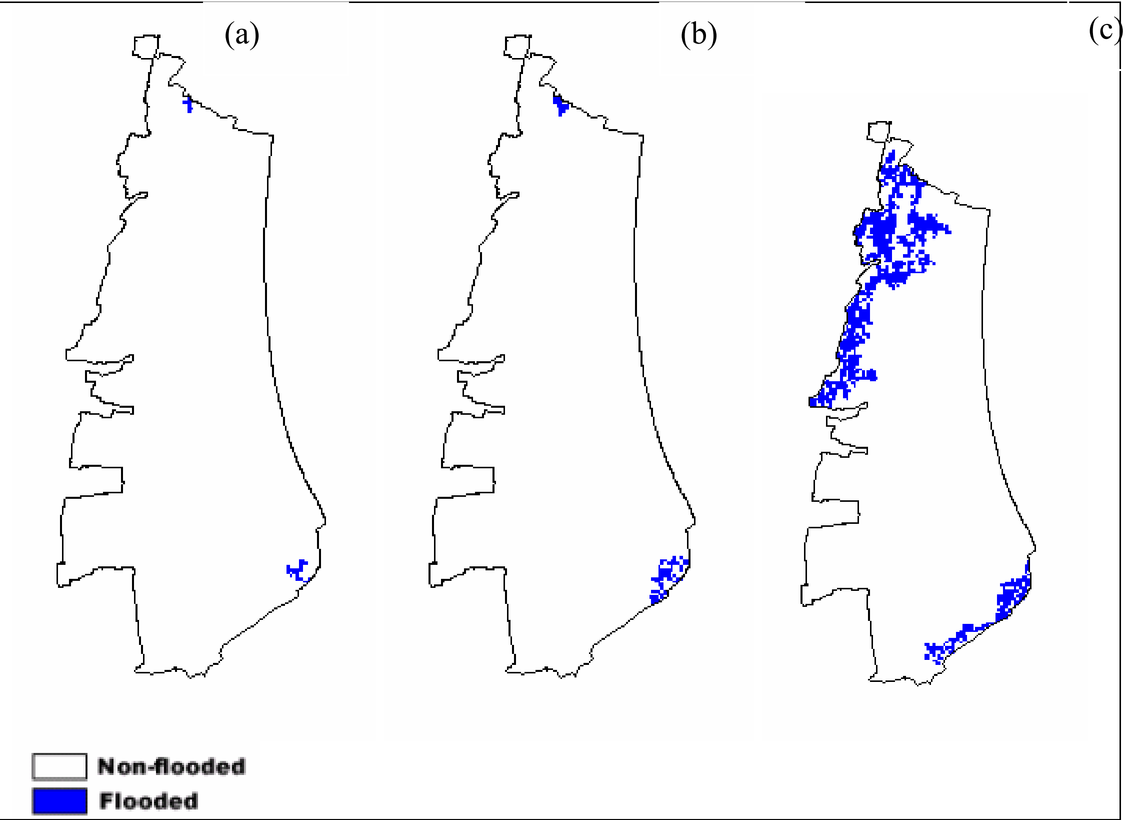



**Figure 25. Estimated area flooded, using a DEM for Cuddalore part of the study area (a) Flood level of 2.0 m (b) Flood level of 3.0 m (c) Flood level of 4.0 m**

Flo

## III. Economics Component

### Tamil Nadu Climate

Based on rainfall distribution, irrigation pattern, soil characteristics, and other physical, economic and social characteristics, Tamil Nadu is classified into seven agro climatic zones: northeast, northwest, west, south, higher rainfall zone, high altitude hilly, and cauvery delta zone. Of these, the most fertile zone is the cauvery delta zone, which is located in the humid tropics. It has a mean annual rainfall of 1,273 mm, mostly contributed by the northeast monsoon.

### Agriculture and Land use

A brief look on the land use pattern and climate scenario in the state will be helpful in analyzing the impacts of climatic change. The following table 15 provides the land use pattern in Tamil Nadu.

**Table 15.** The land utilization in Tamil Nadu

| Sl. No | Details | Area (in m.ha) |
|---|---|---|
| 1. | Forest Land | 2.13 |
| 2. | Barren and uncultivable land | 0.48 |
| 3. | Land put to non agricultural use | 1.98 |
| 4. | Cultivable waste | 0.35 |
| 5. | Permanent pastures and others grazing land | 0.12 |
| 6. | Land under miscellaneous tree crops | 0.24 |
| 7. | Current fallows | 1.09 |
| 8. | Other fallows | 1.14 |
| 9. | Net area sown | 5.46 |
| 10. | Total geographical Area | 12.99 |
| 11. | Area sown more than once | 1.06 |
| 12. | Total cropped Area | 6.52 |

Normal coverage of major agricultural crops in different agro-climatic zones of Tamil Nadu is provided in Table 16. Paddy is the dominant agricultural crop in all the agro-climatic zones occupying more than 30% of the total cropped area in the State. Groundnut is the second dominant crop mostly grown in uplands both during south west and north east monsoon seasons. The low land crops like paddy and sugarcane are frequently affected by drought and water stagnation coinciding with heavy rainfall during north east monsoon season.

**Fig 26. Land utilization in Tamil Nadu**

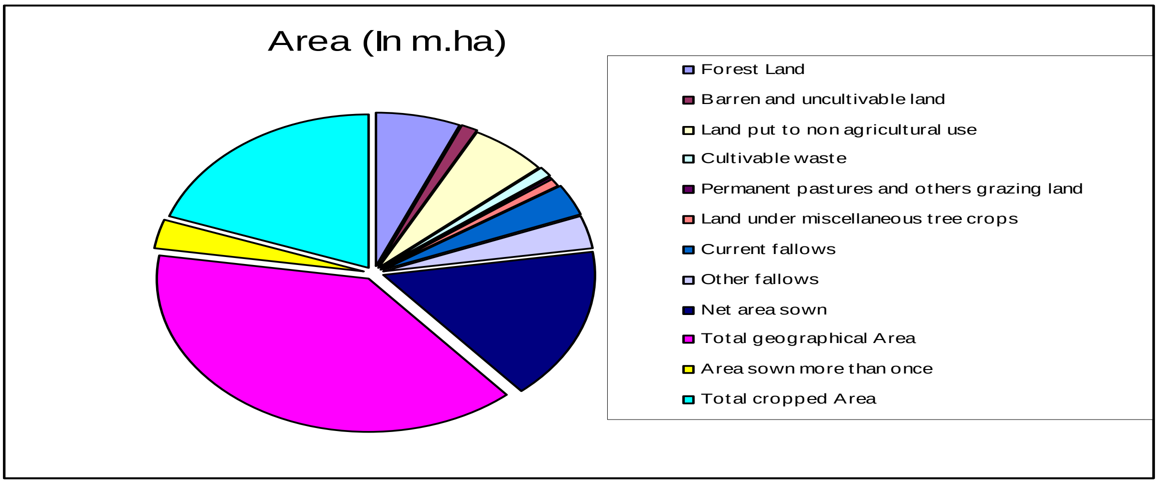



**Table 16. Normal coverage of major crops in Agro climatic Zones of Tamil Nadu (ha)**

| Crops | North Eastern Zone | North Western Zone | Western Zone | Cauvery Delta Zone | Southern Zone | High Rainfall Zone | Total |
|---|---|---|---|---|---|---|---|
| Paddy | 721844 | 122941 | 78784 | 636000 | 576982 | 33661 | 2170212 |
| Jowar | 22022 | 69762 | 101169 | 92312 | 99238 | 0 | 384503 |
| Bajra | 80674 | 11943 | 2899 | 25617 | 47103 | 0 | 168236 |
| Ragi | 20110 | 80850 | 12881 | 482 | 5680 | 0 | 120003 |
| Green Gram | 12359 | 16426 | 9249 | 21466 | 23584 | 3 | 83086 |
| Black Gram | 35349 | 23864 | 4852 | 64065 | 34463 | 1507 | 134100 |
| Sugar Cane | 136029 | 40674 | 38106 | 46572 | 41795 | 0 | 303176 |
| Cotton | 23281 | 43077 | 28242 | 39007 | 98558 | 1 | 232166 |
| Groundnut | 383529 | 212990 | 96224 | 85343 | 121698 | 139 | 899923 |
| Banana | 14959 | 3961 | 10868 | 19319 | 30478 | 4479 | 84064 |
| Mango | 19523 | 34364 | 2824 | 4422 | 26572 | 1754 | 89459 |
| OtherCrops | 191121 | 468070 | 300790 | 222751 | 501724 | 61300 | 1745756 |
| GrandTotal | 1660800 | 1128922 | 686888 | 1257355 | 1607875 | 102844 | 6444684 |

## Rainfall

Agriculture in Tamil Nadu is largely dependent on the success or otherwise of the Monsoons. Both Southwest and Northeast monsoons are crucial for the successful harvest of crops in the state. The state has three distinct rainfall seasons: (1) southwest monsoon (June–September), (2) northeast monsoon (October–January), and (3) dry season (February–May). The state's cropping system centers on the northeast monsoon season. The state has a normal annual rainfall of 979 mm, with 45 rainy days. Table 17 shows rainfall pattern in various districts of the state while figure 27 depicts the trends in annual rainfall of the State. Long term state annual rainfall does not show any significant upward or downward trend and is almost static with annual variations along this long term flat average.

Fig 27.

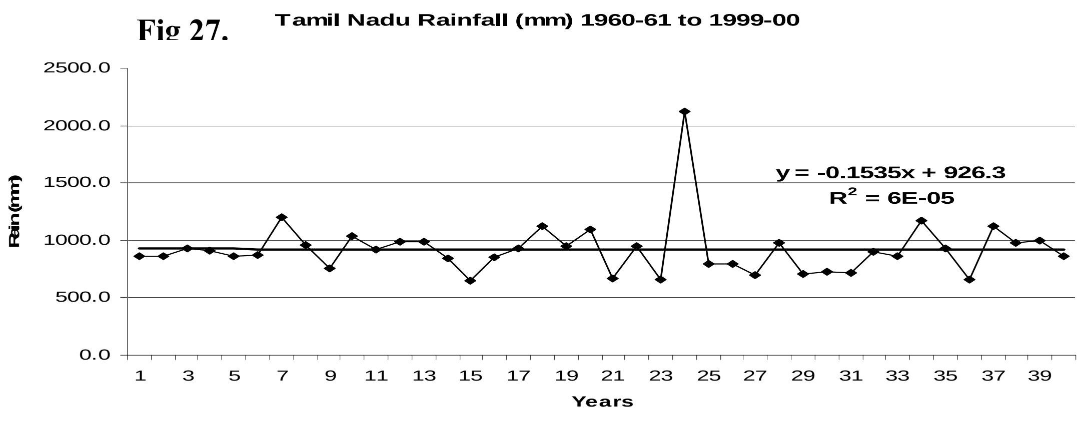
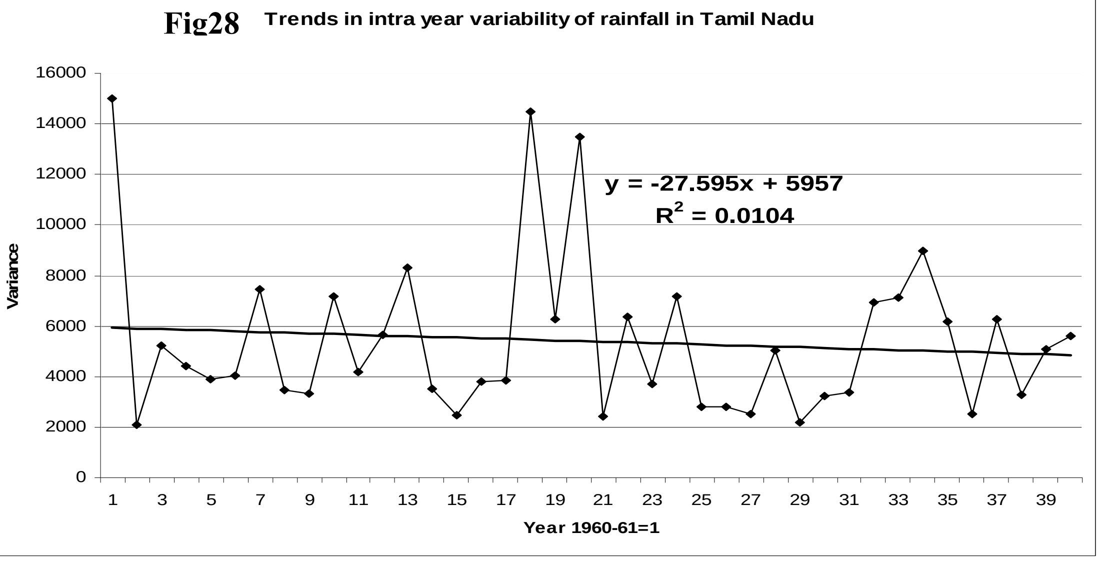



**Table 17. District rainfall in Tamil Nadu**

| S. No | Mean Annual Rainfall (mm) | Districts |
|---|---|---|
| 1 | <800 | Coimbatore |
| 2 | 800-1000 | Pudukottai, Tirunelveli, Ramanathapuram, Madurai, Salem, Dharmapuri, North Arcot, Trichy |
| 3 | 1000-1200 | South Arcot and Thanjavur |
| 4 | 1200-1400 | Madras and Chengleput |
| 5 | 1400-1800 | Kanyakumarai |
| 6 | >1800 | The Nilgiris |

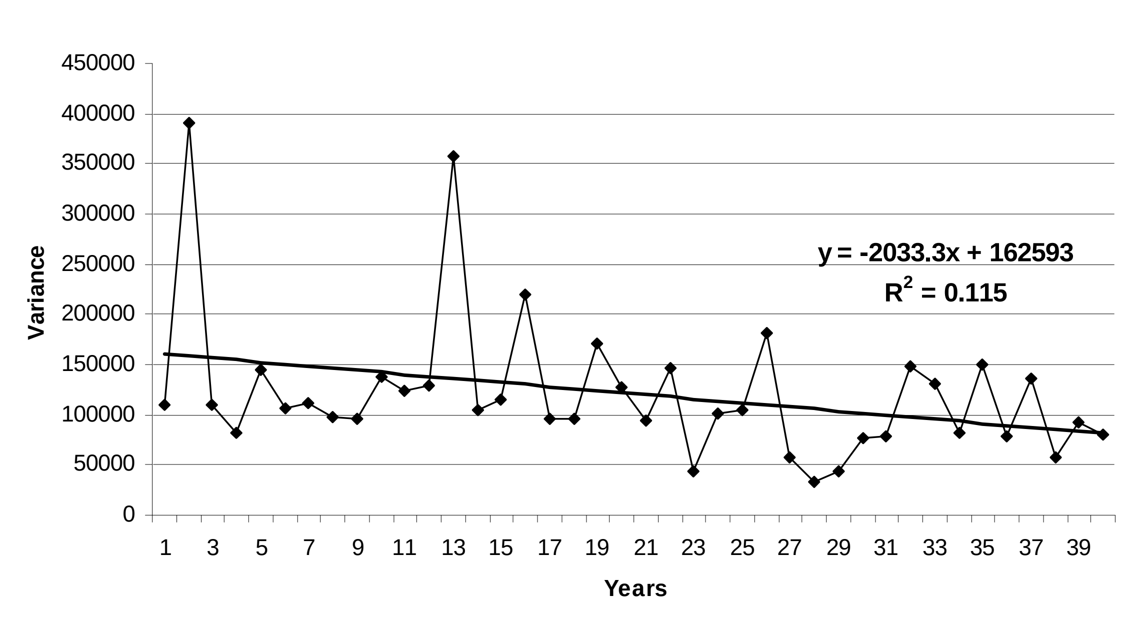
Fig28




Similarly the intra year variability (fig.28) also does not show significant trends, though it exhibits a slightly higher declining trend compared to annual rainfall pattern. Inter district annual variability in rainfall levels(fig.29), however, shows a markedly higher declining

trend. Perhaps this indicates that the rainfall environment of the state is tending towards more homogeneity with ecological and environmental differences being narrowed due to human intervention activities. This also offers scope for Ricardian type analysis.
The northwest zone has an annual rainfall range of 560– 1,080 mm, while the hilly regions receive 1,300 mm annually. Districts like Dharmapuri and Salem, which are in this zone, receive 45% of their annual rainfall from the southwest monsoon. The districts of Periyar, Coimbatore, Salem, and North Madurai are in the west zone, which has a mean annual rainfall of 635 mm. This zone has a semiarid to sub humid climate with frequent droughts. In this region, almost half the rainfall is from the northeast monsoon. The cauvery delta zone has a tropical climate, with a mean annual rainfall of 1,278 mm. The southern zone of Tamil Nadu, comprising the districts of Ramanathapuram, Tirunelveli, Dindigul, South Madurai, and Pudukottai, is under the rain shadow region, having a prolonged dry climate. Only northeast monsoon rainfall is dependable here. Hence, the mean water deficit exceeds rainfall in all months except October and November. Tamil Nadu has 8 drought-prone districts covering 833,997 km2, or about 64% of the total area of the state.

**Fig29**




The drought-prone districts are Coimbatore, Dharmapuri, Kanyakumari, Madurai, Ramanathapuram, Salem, Tirunelveli, and Tiruchchirappalli. Coimbatore district has erratic and unpredictable rainfall. About 30% of the district's annual rainfall is recorded in the southwest monsoon and 50% is contributed by the northeast monsoon through cyclonic activity. Generally, rainfall decreases from north to south. Dharmapuri district has pleasant dry weather, with most of its rainfall coming from the southwest monsoon.
Because of its close proximity to the sea, Kanyakumari has a maritime climate. Here the southwest monsoon begins in June and lasts until September. The rainfall in this region is provided equally by the southwest and northeast monsoons.
In the Madurai region, 29% of the annual rainfall is contributed by the southwest monsoon and 42% by the northeast monsoon. Because of variations in the district's topography, the rainfall is erratic in time and space. A dry and hot climate prevails in Ramanathapuram, with only 24% of the annual rainfall coming from the southwest monsoon and 53% coming during the winter monsoon. Salem district has a dry temperate climate, while Tiruchchirappalli is

predominantly a dry zone, with 33% of its annual rainfall from the southwest monsoon and the rest from the northeast monsoon. Tirunelveli is a hot tropical region with nearly 60% of its annual rainfall occurring from October to December.

**Impact of rainfall variability extremes**

The two monsoons Viz., southwest and northeast monsoon are dominant source of precipitation providing almost 80% of the total annual rainfall. Northeast monsoon is associated with cyclonic storms causing wide spread damage to property. Inter annual rainfall variability causes significant damage to agriculture. The annual co-efficient of variation is around 30%. Despite the inter annual variability, intra seasonal variability also causes frequent crop failures and loss to major agricultural resources.

**Droughts**

Tamil Nadu experiences recurrent droughts. The state normally benefits from northeast monsoon rainfall from October to December, unlike other regions of India, which are dominated by southwest monsoon rainfall. In general, four major parameters determine the nature and extent of drought conditions in Tamil Nadu: (1) rainfall, (2) ground water, (3) reservoir levels, and (4) crop conditions. It is estimated that nearly 50% of the districts in the state are drought prone. The state receives nearly 80% of its annual rainfall during the northeast monsoon, whereas it experienced below-normal rainfall in the southwest monsoon for 30% of the years in the last 25 years. During the southwest monsoon period, water demand always exceeds rainfall, but the water deficit is quite low in the northeast monsoon period. Hence, due to severe water deficit, drought recurs during the southwest monsoon and also in summer months in Tamil Nadu.

Although the northeast monsoon has a major impact on rainfall distribution and cropping patterns in Tamil Nadu, most of the droughts occur in the southwest monsoon or *kharif* season (June–September). An analysis of rainfall from 1871 to 1985 shows 4 consecutive years of deficit rainfall from 1928 to 1931 and 3 consecutive years of deficit rainfall from 1968 to 1970. These had a great impact on ground water levels, reservoir levels, crop conditions, and soil moisture. Sandy soils in the region are more prone to severe drought. Recent droughts occurred in 1966, 1967, 1979, 1982, 1986, 1987, and 1989. Each of these droughts posed different types of problems. Some of the droughts were chronic or severe and some were mild.

During the 1966 drought, there were 2 consecutive weeks of severe drought, and no moderate droughts occurred during the *kharif* season. In 1967, there were 3 severe consecutive drought weeks followed by 3 weeks of moderate drought. In 1979, chronic drought occurred, with 9 consecutive weeks of severe droughts followed by moderate drought weeks, and a similar situation occurred in 1982. The droughts of 1986 and 1987 were also chronic and significant for India as well as Tamil Nadu. The severity and extent of drought in the state is believed to be the result of aberrations in rainfall, overexploitation of ground water, lower reservoir levels, and crop stress conditions. Red, black, and alluvial soil types predominate in Tamil Nadu, but sandy soils in the southeast part of the state are prone to chronic droughts.

**Cyclones**

As is well known, the main source of rainfall for Tamil Nadu is the North Eastern Monsoon (Oct-Dec), which is mainly attributable to the tropical cyclones, which hit the Tamil Nadu coast or come very close to the coast. Table 18 gives the month wise frequency of the cyclonic storms that crossed the TN coast during the period 1891 – 2000. It is seen that during the period of 110 years, 64 cyclones have crossed the Tamil Nadu coast indicating a biennial frequency of one only and the number which intensity into severe cyclone is only half that of the cyclones. Nevertheless there have been considerable severe cyclones, which caused history in terms of the death toll and property loss. The maritime districts which are most affected by the cyclones are Pudukottai and Thanjavur districts, followed by Cuddalore.

**Impact of rainfall variability on irrigation and land use**

Table 19 presents the relationship between rainfall and different sources of irrigation in terms of correlation coefficients among them. Similarly relationships between rainfall levels and land use in terms of cultivated area and production levels of important crops in the state and study area are also presented in table 20.

**Table 18**. Month wise cyclonic storms crossing State coast during 1891 – 2000.

| Month | Frequency CS | Frequency SCS | % Of SCS out of total cyclone |
|---|---|---|---|
| January | 3 | 1 | 33 |
| February | 1 | 1 | 100 |
| March | 1 | - | - |
| April | 2 | 1 | 50 |
| May | 3 | 1 | 33 |
| June | - | - | - |
| July | - | - | - |
| August | - | - | - |
| September | - | - | - |
| October | 6 | 2 | 33 |
| November | 34 | 22 | 64 |
| December | 14 | 8 | 57 |
| Annual | 64 | 36 | 55 |

(CS – Cyclonic Storm, SCS – Severe Cyclonic Storm)

**Table 19. Correlation between rainfall and irrigation sources in districts 60-61 to 1999-00**

| Districts | Canals | Tanks | Others | Open wells | Tube wells | Surface water | Ground water | Total |
|---|---|---|---|---|---|---|---|---|
| Kancheepuram | 0.17 | 0.24 | 0.13 | 0.14 | 0.05 | 0.24 | 0.12 | 0.52 |
| Cuddalore | 0.20 | 0.36 | 0.21 | 0.09 | -0.15 | 0.34 | -0.08 | 0.29 |
| Vellore | 0.24 | 0.49 | 0.22 | -0.17 | -0.17 | 0.46 | -0.18 | 0.44 |
| Salem | 0.51 | 0.23 | 0.10 | 0.33 | 0.33 | 0.42 | 0.33 | 0.40 |
| Coimbatore | 0.13 | 0.34 | -0.15 | 0.17 | -0.07 | 0.14 | 0.15 | 0.19 |
| Trichirappalli | 0.19 | 0.66 | 0.20 | 0.05 | -0.11 | 0.61 | 0.00 | 0.37 |
| Thanjavur | 0.31 | 0.31 | -0.10 | 0.28 | -0.22 | 0.36 | -0.17 | 0.36 |
| Madurai | 0.12 | 0.36 | 0.07 | -0.07 | -0.04 | 0.33 | -0.07 | 0.07 |
| Ramanathapuram | -0.05 | 0.65 | 0.32 | -0.14 | -0.16 | 0.65 | -0.14 | 0.72 |
| Tirunelveli | 0.35 | 0.52 | -0.04 | 0.19 | -0.08 | 0.51 | 0.19 | 0.52 |
| The Nilgiris | -0.32 | -0.22 | 0.39 | -0.06 | 0.16 | 0.35 | -0.04 | 0.33 |
| Kanyakumari | 0.30 | -0.19 | 0.19 | -0.23 | -0.46 | 0.37 | -0.29 | 0.33 |
| STATE | -0.03 | 0.14 | 0.04 | -0.11 | -0.02 | 0.10 | -0.09 | -0.01 |

An interesting result is that in most of the districts rainfall has a positive correlation with the area irrigated by surface sources namely tanks and canals and negative correlation with groundwater irrigated area. Coupled with the fact that over years share of surface sources have declined from 75 to nearly 50 percent and that place has been taken over by wells, and that rainfall remained devoid of any significant trend, this indicates that rainfall variability rather than level of irrigation has greater impact on sources of irrigation.

**Table 20. Regression of cultivated area on rainfall and variability (1960-61 to 1999-00).**

| | Net Area Sown | | | Gross Cropped Area | | | Total Fallow | | |
|---|---|---|---|---|---|---|---|---|---|
| | Intercept | Rain | Variance | Intercept | Rain | Variance | Intercept | Rain | Variance |
| SW | 263261.58 | 160.24 | -1.69 | 332228.30 | 297.17 | -4.39 | 170476.06 | -167.94 | 3.54 |
| | 12.29 | 2.27 | -0.51 | 7.47 | 2.03 | -0.64 | 6.84 | -2.04 | 0.92 |
| NE | 269879.89 | 88.25 | 0.27 | 333141.01 | 181.82 | 0.61 | 169741.29 | -107.60 | 0.29 |
| | 18.81 | 2.58 | 0.50 | 11.40 | 2.61 | 0.56 | 10.05 | -2.67 | 0.46 |
| Monsoon | 227456.37 | 111.39 | -0.23 | 255450.47 | 213.54 | 0.07 | 220985.77 | -139.08 | 1.68 |
| | 10.21 | 3.31 | -0.19 | 5.54 | 3.07 | 0.03 | 8.37 | -3.49 | 1.18 |

Figures in second rows are t values

Though groundwater has begun to raise its share over the decades, surface sources as a whole still retain the dominant share in the State as shown in Table 21. Among the twelve composite districts as many as 10 were dominated by surface irrigation in early sixties, with only Salem and Coimbatore being dominated by groundwater sources. Progressively the position changed. By early eighties three districts Cuddalore, Vellore and Madurai moved under groundwater fold and by early nineties another two districts Kancheepuram and The nilgries followed suit leaving only five districts still dominated by surface sources overall. As already seen in Ramanathapuram and Tirunelveli already the trend is to increase the number and depth of wells and may end up as groundwater dominated soon. In Thanjavur district the situation is turning favourable towards groundwater with growing uncertainties in the receipt of Cauvery waters from the neighbouring State. Efforts are under way to promote alternate crops in the place of rice and may lead to growing dependence on wells in decades to come. Thus over a period of about half a century the share position of surface and groundwater sources seemed to have interchanged positions geographically and quantitatively.

Considering the agro climatic zone wise dominance of the sources of irrigation (Table 22) again, the position is similar. Out of seven identified zones five were dominated by surface sources by early seventies and gradually two more zones moved away leaving only three regions as of late nineties. Two more zones – Cauvery and southern zones- are in the process of change.

**Table 21.** Decadal Change of Agro Climatic Zones over Surface and Ground Water Sources

| 1960-61 | | 1970-79 | | 1980-89 | | 1990-91 | | 1999-00 | |
|---|---|---|---|---|---|---|---|---|---|
| **Surface** | **Ground** | **Surface** | **Ground** | **Surface** | **Ground** | **Surface** | **Ground** | **Surface** | **Ground** |
| North Eastern | | North Eastern | | | North Eastern | | North Eastern | | North Eastern |
| | North Western | | North Western | | North Western | | North Western | | North Western |
| | Western | | Western | | Western | | Western | | Western |
| Cauvery Delta | | Cauvery Delta | | Cauvery Delta | | Cauvery Delta | | Cauvery Delta | |
| Southern | | Southern | | Southern | | Southern | | Southern | |
| High Rainfall | | High Rainfall | | High Rainfall | | High Rainfall | | High Rainfall | |
| High Altitude | | High Altitude | | High Altitude | | High Altitude | | | High Altitude |
| State | | State | | State | | State | | State | |

**Table 22.** Decadal Change of Districts over Surface and Ground Water Sources

| 1960-61 | | 1970-79 | | 1980-89 | | 1990-91 | | 1999-00 | |
|---|---|---|---|---|---|---|---|---|---|
| **Surface** | **Ground** | **Surface** | **Ground** | **Surface** | **Ground** | **Surface** | **Ground** | **Surface** | **Ground** |
| Kancheepuram | | Kancheepuram | | Kancheepuram | | Kancheepuram | | | Kancheepuram |
| Cuddalore | | Cuddalore | | | Cuddalore | | Cuddalore | | Cuddalore |
| Vellore | | Vellore | | | Vellore | | Vellore | | Vellore |
| | Salem | | Salem | | Salem | | Salem | | Salem |
| | Coimbatore | | Coimbatore | | Coimbatore | | Coimbatore | | Coimbatore |
| Thiruchirapalli | | Thiruchirapalli | | Thiruchirapalli | | Thiruchirapalli | | Thiruchirapalli | |
| Thanjavur | | Thanjavur | | Thanjavur | | Thanjavur | | Thanjavur | |
| Madurai | | Madurai | | | Madurai | | Madurai | | Madurai |
| Ramanathapuram | | Ramanathapuram | | Ramanathapuram | | Ramanathapuram | | Ramanathapuram | |
| Tirunelveli | | Tirunelveli | | Tirunelveli | | Tirunelveli | | Tirunelveli | |
| The Nilgiris | | The Nilgiris | | The Nilgiris | | The Nilgiris | | | The Nilgiris |
| Kanyakumari | | Kanyakumari | | Kanyakumari | | Kanyakumari | | Kanyakumari | |
| State | | State | | State | | State | | State | |

**Ricardian type regressions: Modeling approach for the study**

Integrated assessment combining insights of many disciplines is used as a primary climate change study tool in order to follow the causal chain of events from perturbations in the environment (greenhouse gas emissions) to the final outcomes (damages to society). Agriculture is one of the primary sectors contributing to and affected by climate change. Changes in atmospheric gaseous concentrations directly and through changes in temperatures and rainfall indirectly affect agricultural production. Three approaches have been widely used in the literature to measure the sensitivity of agricultural production to climate change; cross-sectional models, agronomic-economic models, and an agro-ecological zone (AEZ) model.

Climate change is essentially a long term phenomenon and is supposed to be gradual in its impact for most part. The agronomic and agro-ecological zone models essentially seek to quantify the impact of these anticipated changes on agricultural production systems mostly by simulating these changes under controlled conditions. Economic components are added subsequently to amplify these effects to larger areas and in terms of economic impact. Cross sectional models differ in essence from these models by recognizing that during the process of climate change the systems subjected to such changes do tend to evolve to minimize the risks involved and stakeholders in these systems do tend to adapt through technological and various other options. The cross-sectional studies suggest that adaptation could mitigate crop losses in developing countries and add to gains in developed countries. The overall result is that global warming is expected to have only a small affect on aggregate global output when adaptations are taken into account.

The cross-sectional approach examines farm performance across climate zones. The technique has been named the Ricardian method because it is inspired from an observation by Ricardo that land values would reflect land productivity at a site (under competition) implying adaptations to environmental and related changes. Because these adaptations benefit the farmer, there is every reason to expect that they will occur. Crucial adaptation strategies include optimal crop switching and related management options including technological innovations leading to an optimal income from the land under given environmental conditions which through. And land values are supposed to reflect the present value of this rental stream. In effect value of land represents capitalization of the rental stream as

$$V=R/i$$

Where v is the value of land, R the rental value of land completely adapted in its use for climate changes and is the rate at which the future rental stream is discounted.

The approach has been used to value the contribution environmental measures make to farm income by regressing land value on a set of environmental inputs especially rainfall and temperature. The approach has been applied to the United States, and Brazil. Here the crucial variables are the value of land and climate parameters as adaptation takes place instantaneously. A corollary of the approach has also been used in India where annual net revenue was substituted for land value. It is a practical alternative when land markets are not active and land values could not be easily observed. Moreover, in cross sectional analysis based on primary data as is done in some studies it may provide a better opportunity to observe the actual productive capacity of land. This approach is more common when the attempt is to assess adaptations to climate change in a single sector land use namely agriculture for crop production. This is perhaps justifiable when applied to developing countries where agriculture is still a major sector in terms of income, employment and land use.

In the Ricardian analysis, prices of both inputs and outputs are assumed to remain proportionately constant. Climate parameters in Ricardian models are usually, rainfall and temperature and Carbon fertilization effects of climate change are not included. Usually climate normals, based on time series averages over a fairly long period of time are considered.

A major consideration in the application of the Ricardian models is the scale. Major available studies concentrate on large countries that have large number of divisions that also differ in climatic levels so that adaptation impacts across these levels could be analysed. Thus the prime requirement of Ricardian models is the availability of sufficiently different climate levels and corresponding land use and value patterns. The major problem then is that such regions differ not only in climate pattern but also differ in other environmental patterns like soil types, technology levels etc. Hence most of the Ricardian models necessarily incorporate control variables to account for such variations as well.

The present study, is an attempt to analyse the impact of climate change in the Ricardian sense discussed above on major crops of the Tamil Nadu State. As will be discussed later, the State has sufficiently large geographical region to meaningfully differentiate them in terms of climatic variations and yet compact to assume homogeneity in term of factors like prices, socio cultural leanings of the population etc.

The model that is used in the study is a slight variation of the types discussed above and used by others and logically follows from the observation "crucial adaptation strategies include optimal crop switching and related management options including technological innovations leading to an optimal income from the land under given environmental conditions". The implication is that when climate changes are perceived it triggers a set of adaptations, in terms of management options. For example, sowing times for a crop may be adjusted, irrigation methods could be changed, new varieties of a crop may be used and there is any number of such minor incremental management options available to cope with changes.

Rational decision making can thus be assumed to result in a set of options to maximize productivity under a given environment. Let this be represented as,

$Y = f(Z)$

where Y is the optimized productivity given the environmental conditions represented by the vector z and f is the set of management options that maps Z on Y. The first level impact of climate change can therefore be thought as Ricardian type impacts of Z on optimal productivity. Ricardian type cross sectional envelope analysis, similar to studies that relate Z to net revenue can then be used to relate Z to productivity levels.

Next level of adaptations occurs when actual crop switching takes place. In a cross section such crop switching will get reflected in the total area devoted to the crop under a given production environment. In any given location there may be short term area fluctuations induced by factors other than Z, however, it is reasonable to assume that averages would reflect adaptations to Z. This may be represented as

$A=f(Z)$

where A is the rational land allocation to a crop under given environmental conditions. In the present study Ricardian type envelope analysis of area and productivity of five major crops cultivated across districts of the Tamil Nadu state were undertaken. This logically leads to an estimation of the production levels.

As mentioned earlier, Z variables are climate normals, calculated as long term averages. Rainfall and temperature are the variables commonly used in climate change impact studies. In this study, rainfall, minimum temperature, maximum temperature and diurnal variations are used. Their logn term versions and annual versions are also used. Y and A of the above functions, are from panel data. Since Y and A are from panels, they are influenced not only by long term term Z variables, but are also influenced by other variables related to cross sections and time series. Hence additional variables to account for such variations are included in the analysis. Sources, computation and usage of the variables employed in the analysis are discussed in the subsequent section.

**Data, sources and variables**

There are presently 28 districts in the state which have come into existence on occasional splits in erstwhile districts. Districts have been used as the cross sectional units in the present study. When data are gathered over geographical locations, not all data originate from the same source and may have different perspectives. It is therefore necessary to pay attention to make them conformable. For instance, weather data is usually associated with recording stations while others on cropping aspects relate to administrative units.

In this study data from three major sources are used. Cross sectional data on cropping aspects, land use, irrigation details and inputs usage were collected from official publications of Government of Tamil Nadu, including Tamil Nadu-An Economic Appraisal, Statistical abstract, and Season and crop report. Data from various volumes were compiled to form a panel data set for crop area, yield, irrigated area under different crops and sources, and total cropped areas for different districts over years.

For climate variables data IMD data set was used. Time series data on daily rainfall, maximum temperature and minimum temperature for 29 locations spread over Tamil Nadu was obtained from IMD, Pune. These data were processed and compiled into a panel set by computing monthly, seasonal and annual averages. These data were made confirmable to the district level panel data based on cluster approach. Whenever a recording station fell completely within an administrative district its data was taken to represent data for that district. When a district has more than a station, their averages were taken to represent the district data. Wherever administrative districts did not have any recording station, averages of the stations falling in the surrounding districts was taken to represent the district level data.

Based on data availability for various variables considered for the analysis the panel data set was constructed for the period from 1990-91 to 2000-2001. For districts that came into existence later than 1990-91 data was used from the years it was made available and thus the panel is essentially an unbalanced panel, though with most districts having the full years data. For computing the climate normals for the districts however, data for the period from 1971-2001 (for 30 years) obtained from IMD was considered.

As discussed earlier, dependent variables considered for analysis are areas and yields of crops paddy, sugarcane, and groundnut that account for major cultivated area of the state besides being grown in almost all districts. To account for Ricardian type climate variables, 30 year averages of rainfall, minimum and maximum temperatures and diurnal variations were included as the independent variables. Though several variants in terms of seasonal averages, monthly averages were tried, in general, the results were qualitatively the same. Hence the final set of climate normals included in the analysis are long term annual rainfall averages (R_LT), minimum temperature (L_LT), maximum temperature (H_LT) and diurnal variation (Diu_LT).

Besides long term averages of climate variables, their annual averages were also included to account for and control annual variations of area and yields. Here again after extensive trials actual annual value counterparts (yearly rainfall (R_Y), minimum temperature (L_Y), maximum temperature (H_Y) and diurnal variation (DiuY) ) of the climate normal variables were retained as a common set of regressors.

Land use in terms of cropped area, proportion under given crops is a set of variables used in the analysis and again plays a more significant role as indices for development levels of the districts in terms of agriculture versus other sectors. Similarly, gross irrigated area, area of crops irrigated and proportion of irrigated area variables are used as controls for district level variations in terms of their actual levels and also as proxies for public and private investments to aid agricultural production in the districts. Several variants of these variables and their interactions were tried and the final results of the analysis are presented in the next section.

Finally, data from HADCM3 climate change projections for Tamil Nadu region downloaded and extracted from the GCM outputs of IPCC SCENARIOS subdirectory available from the internet site http://ipcc-ddc.cru.uea.ac.uk/sres/hadcm3_download.html was used in the Ricardian type regressions to estimate the impact of climate change on the area, yield and production levels of the crops analyzed.

From the site contains mean monthly values on climatic parameters precipitation, maximum mean daily temperature and minimum mean daily temperature.

• The timeslice of parameters are:

* 1961-1990 Mean monthly values considered as BASELINE period (1980)

* Mean monthly change fields i.e. difference from BASELINE

# 2010-2039 Mean monthly change fields refered as 2020

# 2040-2069 Mean monthly change fields refered as 2050

The grid size is 3.75 Degrees in Longitude and 2.5 Degrees in Latitude. These grids divide Tamil Nadu region into six zones and the data were assigned to the corresponding districts falling predominantly to these zones. As per the HADCM3 climate change projections different regions of Tamil Nadu are expected to experience changes over the next century in terms of rainfall and temperatures. During Southwest monsoon, rainfall is expected to increase in the southern parts of Tamil Nadu, while it is expected to decrease in the central regions and unchanged in the northern parts of Tamil Nadu. During Northeast monsoon rainfall is expected to decrease in the central parts of Tamil Nadu, and not much change is expected in southern and Northern parts. Both maximum and minimum temperatures are expected to rise by 2 to 5 degree Celsius in the State. Warming is expected to be more in the central and north eastern parts of Tamil Nadu.

Annual average differences of corresponding projections were used to adjust the existing average levels of the Ricardian long term and annual climate variables to arrive at baseline adjusted future values. These values in turn were used in the Ricardian type regressions along with existing mean levels of other control variables to estimate the area, yield and productivity levels of crops under A2 scenario of climate change.

**Suitability of the Ricardian type model for the present study**

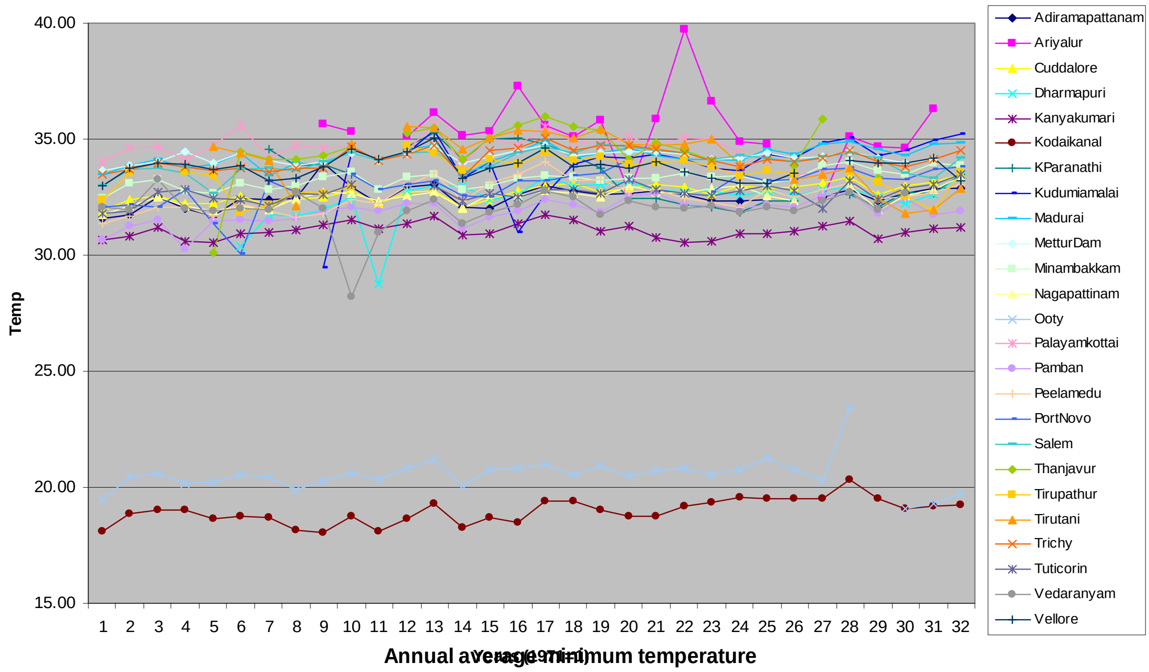
Basic requirement for Ricardian type analysis is availability of diverse geographical cross sections that differ in climate variable averages that differ atleast to the extent of their changes anticipated for a given region. The idea is that these cross sectional differences represent adjustments to anticipated climate changes over long run for a given location. Thus if the anticipated temperature change is 2$^{o}$C due to climate change, then comparing two cross sectional regions that differ now by 2$^{o}$C would give an idea of how the lower temperature region would do when it attains the temperature level of the high temperature region. A feasibility test for running Ricardian type model is to chart examine whether the cross section sample proposed to be analyzed exhibits such differences. To this end data relating to climate variables minimum and maximum temperatures, diurnal variation and rainfall are presented in the following figures. Their long term averages at different locations corresponding to the stations are also presented in table 23.

It is seen from the table as well as figures that there is sufficient variations across regions of Tamil Nadu that account for far more variations than changes anticipated by the HADCM3 projections over different regions of Tamil Nadu. Rainfall varies from an annual average minimum of about 400 mm to more than 1500 mm. Minimum temperature varies from (after excluding hill stations Ooty, Coonoor and Kodaikanal) 21.24°C to 25.87°C, maximum temperature from 31.07°C to 35.44°C and diurnal variation from 7.37°C to 13.61°C. Not only there are sufficient cross sectional variations in climate variables, but these variations are also mostly consistent over years as can be seen from the figures. Thus, it appears reasonable that Ricardian type analysis could be undertaken using Tamil Nadu State as study area with districts treated as cross sectional units.

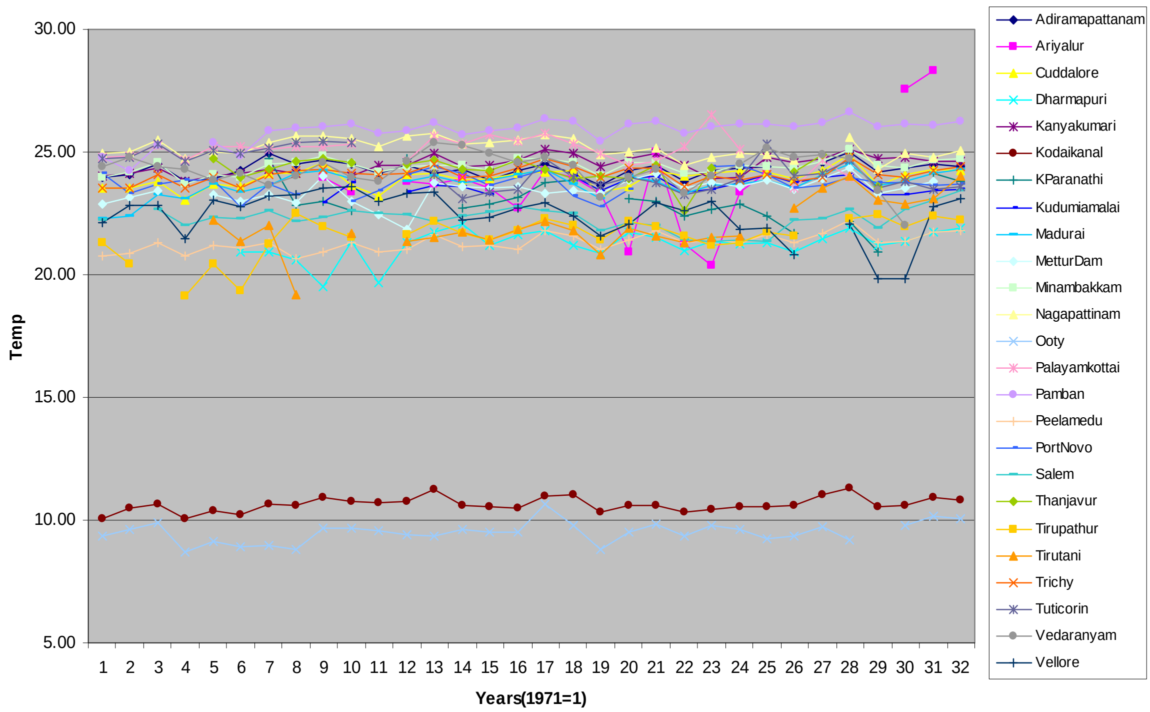
**Table 23. Cross sectional annual averages of climate variables across State**

| Stations | Rainfall | Tmin | Tmax | Diurnal |
|---|---|---|---|---|
| Adiramapattanam | 1169 | 24.29 | 32.52 | 8.21 |
| Ariyalur | 393 | 23.75 | 35.44 | 11.81 |
| Coonoor | 1401 | 12.45 | 21.97 | 9.50 |
| Cuddalore | 1222 | 23.95 | 32.70 | 8.74 |
| Dharmapuri | 811 | 21.24 | 32.44 | 10.95 |
| Kallakurichi | 719 | 23.24 | 33.82 | 13.61 |
| Kanyakumari | 721 | 24.47 | 31.07 | 6.80 |
| Karaikudi | 713 | 24.08 | 33.74 | 10.78 |
| Kodaikanal | 1562 | 10.64 | 18.96 | 8.32 |
| KParanathi | 594 | 23.01 | 33.41 | 11.56 |
| Kudumiamalai | 890 | 23.61 | 33.92 | 10.51 |
| Madurai | 829 | 23.71 | 34.27 | 10.56 |
| MetturDam | 885 | 23.42 | 34.22 | 10.94 |
| Minambakkam | 1401 | 24.41 | 33.28 | 8.84 |
| Nagapattinam | 1317 | 25.16 | 32.51 | 7.37 |
| Ooty | 1058 | 9.50 | 20.52 | 11.01 |
| Palayamkottai | 724 | 25.06 | 34.62 | 9.56 |
| Pamban | 914 | 25.87 | 31.88 | 5.82 |
| Peelamedu | 599 | 21.31 | 32.54 | 11.27 |
| PortNovo | 1132 | 23.72 | 32.96 | 8.84 |
| Salem | 944 | 22.29 | 34.02 | 11.85 |
| Thanjavur | 885 | 24.26 | 34.51 | 9.29 |
| Tirupathur | 861 | 21.56 | 33.44 | 11.73 |
| Tiruporur | 824 | 24.80 | 31.98 | 13.08 |
| Tirutani | 879 | 22.02 | 34.19 | 12.08 |
| Trichy | 838 | 24.08 | 34.16 | 10.03 |
| Tuticorin | 589 | 24.27 | 32.67 | 8.40 |
| Vedaranyam | 1302 | 24.27 | 31.99 | 7.86 |
| Vellore | 952 | 22.43 | 33.81 | 11.37 |

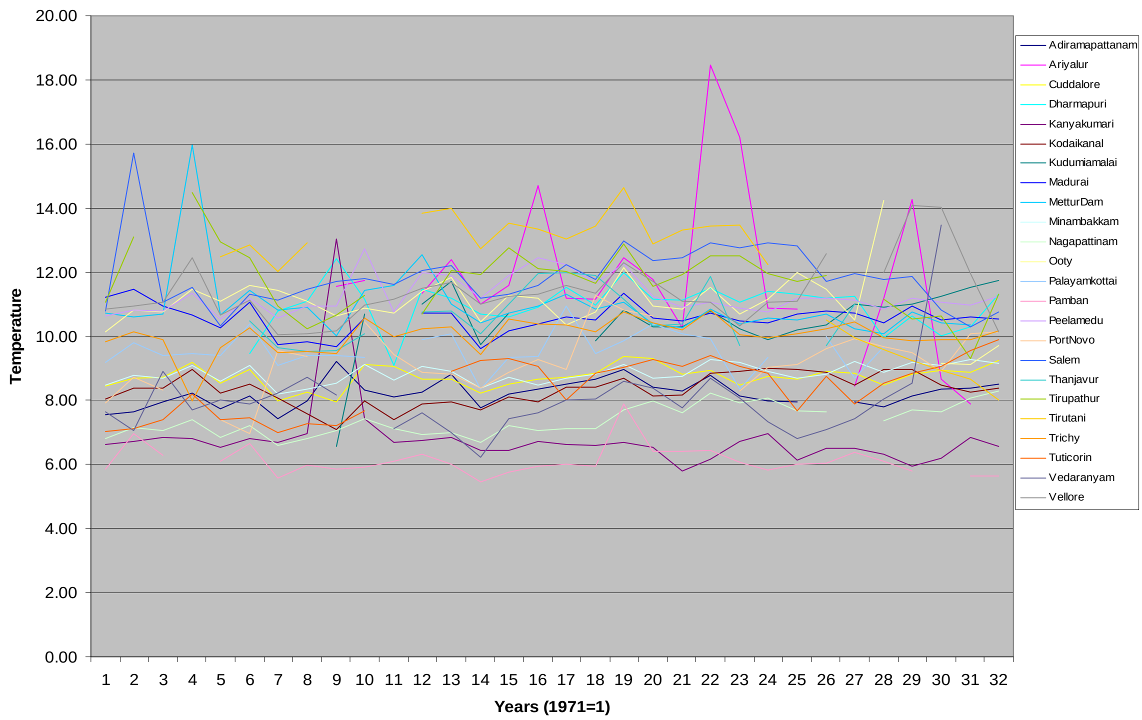
**Annual average Maximum temperatures**



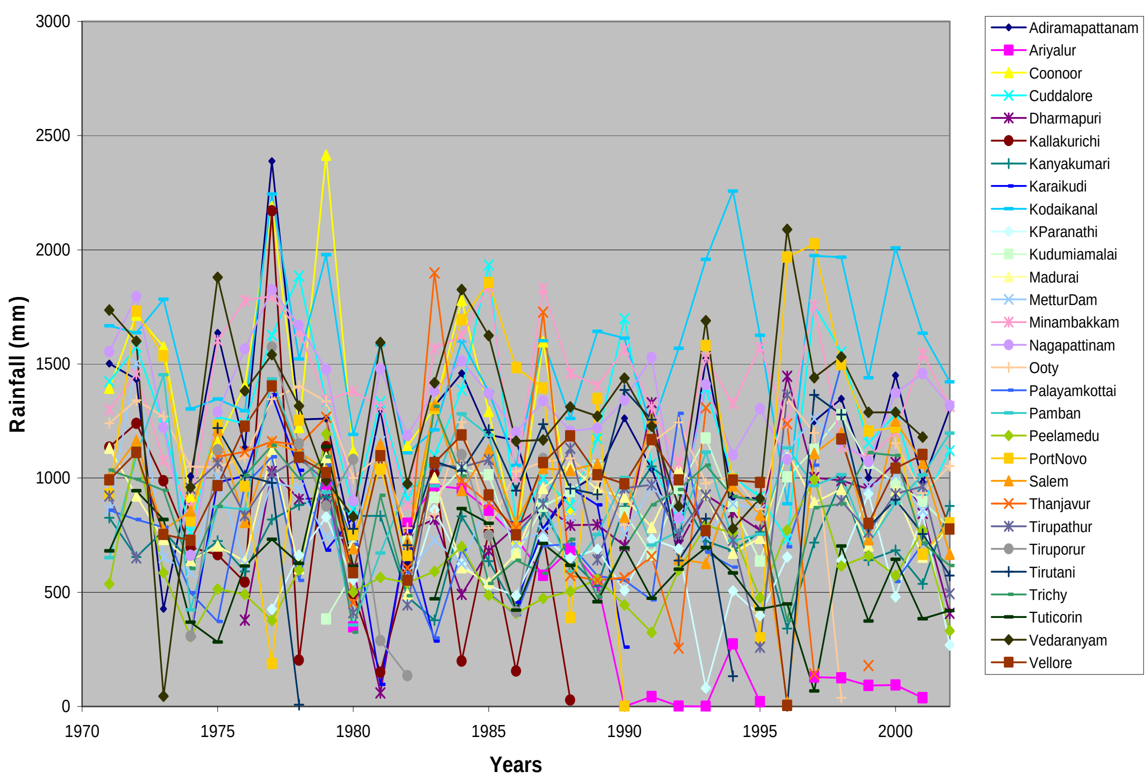

**Annual average minimum temperature**



## Diurnal temperature variation




## Average annual rainfall (mm)



**Ricardian type regression results**

Based on specifications and variables discussed earlier several versions of regressions were tried and following uniform specifications were adopted finally for all the crops. Separate specifications were used for modeling area ($A_i$) and yield ($Y_i$).

**Ricardian type area regressions**

$A_i$ = f (TOTCROP_, PRO_IA, R_LT, R_Y, L_LT, L_Y, H_LT, H_Y, DIU_LT, DIU_Y, C_Y)

**Ricardian type productivity regressions**

$Y_i$ = f (TOTCROP_, PRO_IA, PRO_SUR_, R_LT, R_Y, L_LT, L_Y, H_LT, H_Y, DIU_LT, DIU_Y, $C_i$_A, $C_i$_IA, PR$C_i$_IA)

Where i = paddy, sugarcane, groundnut and other variables used above and their units of measurements are explained in table 24.

**Table 24. Variables used in the regressions**

| Variable | Explanation | Unit |
|---|---|---|
| TOTCROP_ | Total cropped area in the district | Ha |
| PRO_IA | Proportion of irrigated area to total cropped area | |
| PRO_SUR_ | Proportion of surface irrigated area from tanks and canals | |
| R_LT | Long-term rainfall average | mm |
| R_Y | Annual rainfall | mm |
| L_LT | Long-term daily minimum temperature average | $^oC$ |
| L_Y | Annual daily minimum temperature average | $^oC$ |
| H_LT | Long-term daily maximum temperature average | $^oC$ |
| H_Y | Annual daily maximum temperature average | $^oC$ |
| DIU_LT | Long-term daily diurnal temperature variation average | $^oC$ |
| DIU_Y | Annual daily diurnal temperature variation average | $^oC$ |
| Crop_A | Area under ith crop | Ha |
| Crop_IA | Irrigated area under $i^{th}$ crop | Ha |
| PRCrop_IA | Proportion of irrigated area under $i^{th}$ crop | |
| Crop_Y | Yield of $i^{th}$ crop | Kg/tonnes |

**Regression results**

The yield regression results are presented in table 25 and area regression results are presented in table 26. The regressions were estimated through OLS. Regressions for area are generally better fits compared to yield regressions. While the explanatory power of the included variables as indicated by the R square values ranged from 0.59 to 0.78 in case of area regressions, it ranged from 0.22 to 0.50 in the case of yield regressions. Area response in general is more predictable, being a somewhat long run decision within complete control of the decision makers, whereas yields are affected by more variables many beyond the control of the decision makers. From an adaptation point of view area responses perhaps are more indicative of the behavior of the decision makers than yield responses. In case of yield response regressions also the explanatory power is low only in the case of groundnut and to some extent in paddy and sugarcane is about 0.36 and 0.50 respectively. A comparison with earlier studies of this nature covering wider geographical averages indicates that the explanatory power of the models are reasonable.

Paddy and sugarcane come to the purview of price and procurement regulations while groundnut being oilseeds come under the purview of developmental programmes. Almost all sets of variables included in both sets of regressions, cropping area related variables, irrigation variables, and most importantly annual and long term climate variables exert significant influences on the dependent variables as indicated by their respective t ratios. But, their influences vary between area, yields and across crops. This indicates that the nature of crops, geographical specificities is characterized by location specific influences. It may therefore be difficult to generalize the impacts of influence of any given set of variables except perhaps through regional averages. Results of individual crop regressions are broadly as follows.

**Paddy**

Included regressors had a very high explanatory power on paddy area with an R square of 0.78. Long term climate variables all have highly significant impact but in a mixed way. Results indicate that any long term average rise in rainfall and high temperature will have positive impacts on paddy area while similar long term diurnal variations will have a negative effect. Among annual averages of this climate variables long term annual rainfall, long term high temperature and proportion of irrigated area has a significant positive impact on paddy area. Irrigation has a positive influence on paddy area.

Paddy productivity regressions have an explanatory power of about 36 percent variations across districts and time span wherein proportion of irrigated area, appear to positively influence paddy yields. Climate variables, both long term minimum temperature and rainfall seem to have marginally negative impact except annual rainfall and long term high temperature and diurnal variation have positive influences.

**Sugarcane**

Area under sugarcane is positively influenced by gross irrigated area, proportion to the irrigated area, long term high temperature and long term average rainfall. Variables like long-term low temperature, annual minimum temperature, both long term and annual diurnal variation and yield of sugarcane shows negative relation ship with the dependant variable. Productivity of sugarcane is positively and significantly influenced by proportion to the irrigated area, long term annual rainfall, both long term and annual high temperature and area under the crop. Variables like proportion of surface irrigated area, long term minimum temperature, both long term and annual diurnal variation and crop irrigated area have negative impact on sugarcane productivity.

**Groundnut**

Area under groundnut is influenced positively by gross cropped area, proportion to the irrigated area, long term high temperature and long term annual rainfall and negatively by annual rainfall, both long term and annual minimum temperature, annual maximum temperature, long term and annual diurnal temperature variation and yield of the crops. Productivity is positively and significantly influenced by crop irrigated area, proportion to the crop irrigated area, proportion to the total irrigated area, long term low temperature and long term diurnal variation and negatively by the proportion to the surface irrigated area, annual minimum temperature, long term high temperature and annual diurnal variation.

**Table 25. Yield regression results**

| Variable | Paddy | | Sugarcane | | Groundnut | |
|---|---|---|---|---|---|---|
| | Co-efficient | t-ratio | Co-efficient | t-ratio | Co-efficient | t-ratio |
| Constant | 6916.9490 | 4.3130 | -1489.301 | -5.4210 | 642.8041 | 0.6160 |
| TOTCROP_ | 0.0004 | 0.6450 | 0.0004 | 2.8400 | 0.0008 | 1.6010 |
| PRO_IA | 417.0316 | 0.8250 | 260.047 | 2.4610 | 781.8029 | 1.9430 |
| PRO_SUR_ | -304.2941 | -1.0810 | -77.316 | -1.3290 | -534.6172 | -2.4860 |
| R_LT | -0.8533 | -2.0640 | 0.204 | 2.0900 | 0.0002 | 0.0010 |
| R_Y | 0.3161 | 1.8150 | 0.010 | 0.2520 | 0.0939 | 0.6510 |
| L_LT | -110.7259 | -0.2060 | -691.273 | -8.8530 | 622.0547 | 2.2190 |
| L_Y | 14.6799 | 0.1150 | 20.875 | 0.7050 | -178.1781 | -1.7140 |
| H_LT | 197.1293 | 0.3800 | 626.316 | 8.4500 | -563.2732 | -2.0950 |
| H_Y | -153.2224 | -1.1830 | 56.678 | 1.8710 | 147.0456 | 1.3800 |
| DIU_LT | -201.7117 | -0.3910 | -581.838 | -8.5000 | 461.5864 | 1.8840 |
| DIU_Y | 10.9496 | 0.1360 | -12.532 | -0.6660 | -49.5417 | -0.7470 |
| Crop_A | -0.0217 | -3.1050 | 0.035 | 2.6510 | -0.0138 | -3.5830 |
| Crop_IA | 0.0199 | 2.9860 | -0.042 | -3.2610 | 0.0178 | 2.7780 |
| PRCrop_IA | -393.6766 | -1.8810 | 525.293 | 1.2050 | 1011.4512 | 2.0420 |
| R square | 0.36 | | 0.50 | | 0.22 | |
| Adj R square | 0.33 | | 0.47 | | 0.18 | |

**Table 26. Area Regression results**

| Variable | Paddy | | Sugarcane | | Groundnut | |
|---|---|---|---|---|---|---|
| | Co-efficient | t-ratio | Co-efficient | t-ratio | Co-efficient | t-ratio |
| Constant | 9727.25 | 0.32 | -43406.01 | -5.02 | -133394.05 | -4.10 |
| TOTCROP_ | 0.10 | 8.38 | 0.03 | 11.23 | 0.18 | 14.12 |
| PRO_IA | 146328.39 | 12.33 | 6909.47 | 2.25 | 985.37 | 0.08 |
| R_LT | 46.34 | 3.69 | 11.39 | 3.50 | 11.31 | 0.84 |
| R_Y | 8.28 | 1.49 | -0.82 | -0.57 | -0.49 | -0.08 |
| L_LT | -50381.50 | -4.59 | -5778.53 | -1.86 | -21392.99 | -1.87 |
| L_Y | -1086.88 | -0.27 | -913.10 | -0.88 | -2146.40 | -0.49 |
| H_LT | 50782.13 | 4.94 | 7052.39 | 2.42 | 24530.13 | 2.27 |
| H_Y | 597.42 | 0.15 | -97.94 | -0.09 | -59.13 | -0.01 |
| DIU_LT | -57854.79 | -5.94 | -4323.64 | -1.61 | -14282.26 | -1.43 |
| DIU_Y | 653.93 | 0.26 | -94.13 | -0.14 | -414.81 | -0.15 |
| Crop_Y | -8.25 | -4.45 | -4.91 | -2.35 | -3.77 | -1.49 |
| R square | 0.78 | | 0.59 | | 0.64 | |
| Adj R square | 0.77 | | 0.58 | | 0.63 | |

**Projections: Baseline and on climate change as per HADCM3 A2 scenario**

Existing base level area and yields are obtained by substituting average values of the explanatory variables for each district in the area and yield regressions. Production levels could then be obtained as their product. Similarly, area and yield levels post HADCM3 A2 scenario climate change could be obtained by substituting base line linked climate variables (as discussed under data and variables section above), in respective regressions and assuming other variables at their current long term base levels. Production estimates could be obtained as the product of estimated area and yield levels. Such computations of base level area, yield and production and their 2020 and 2050 counterparts based on climate change were done for individual districts and then summarized for the state and the final production results for the crops considered under climate change scenarios is presented in table 27.

**Table 27. Impact of A2 climate change scenario on production of major crops in Tamil Nadu**

| **Production (Lakh tonnes)** | | | | | |
|---|---|---|---|---|---|
| | **Existing** | **2020** | **% Change** | **2050** | **% Change** |
| Paddy | 76.06 | 69.32 | -8.86 | 66.52 | -12.55 |
| Sugarcane | 275.28 | 215.86 | -21.58 | 218.19 | -20.74 |
| Ground Nut | 22.49 | 19.83 | -11.80 | 20.51 | -8.81 |
| **Area (Lakh Hectare)** | | | | | |
| | **Existing** | **2020** | **% Change** | **2050** | **% Change** |
| Paddy | 22.39 | 21.15 | -5.54 | 20.52 | - 8.35 |
| Sugarcane | 3.28 | 2.97 | - 9.45 | 2.87 | - 12.50 |
| Ground Nut | 12.89 | 12.23 | -5.12 | 12.42 | - 3.65 |
| **Yield (Kg/ha) , * (t / ha)** | | | | | |
| | **Existing** | **2020.00** | **% Change** | **2050.00** | **% Change** |
| Paddy | 3397.32 | 3277.68 | - 3.52 | 3241.86 | - 4.58 |
| Sugarcane* | 83.93 | 72.68 | - 13.40 | 76.02 | - 9.42 |
| Ground Nut | 1745.04 | 1622.10 | -7.04 | 1651.58 | -5.36 |

Overall, climate change in terms of rainfall and temperature changes under A2 scenario of HADCM3 model appear to have negative impact on the area and productivity of major crops in Tamil Nadu. Medium term projections for 2020 based on Ricardian type regressions indicate that climate change impacts are ranged from about 4 percent reduction in productivity of paddy to 13.4 percent decline in sugarcane productivity. In general, in the long term impacts of climate change on area and productivity in 2050 are decreasing minimum of about 4 percent in area under groundnut to the maximum of 12.5 percent in sugarcane area as observed from the table 27.

Major food crop paddy is projected to decrease both in terms of area and productivity, resulting in lower production levels of about 13 percent in 2050 from existing average levels and 9 percent in 2020. Productivity decreases are less than the area decrease in both medium and long term climate change effect. Being the major food crop, efforts have been focused around evolving better varieties to suit varied production environments and also to improve the production environment itself in terms of providing better irrigation facilities and crop management. It has been the single largest crop grown in the state and the largest water uses as well. It is conceivable that such efforts would continue in the near future as well to adapt to any adverse impact of climate change and is perhaps reflected in the decrease of paddy production about 13 percent in 2050 under Ricardian type regression based projections.

Sugarcane being a major sugar producing crop in the state projected to decrease about 9.45 and 13.4 percent in terms of area and productivity in short term and about 13 and 9 percent in terms of area and productivity in the long term. Sugarcane production projections indicate a decline of 21.58 percent in the medium term and a 20.74 per cent decline in the long term impact of climate change, the decline being contributed by both area and productivity reduction almost similarly both in the medium and long term.

Groundnut, as a major oil seeds, is projected to face decreased production in both short and long term. Groundnut, which is the predominant source of edible oils of the Tamil Nadu state is the least climate change impacted crops among those presently analyzed in terms of productivity and production in the long term impact. Area under groundnut projected to decrease about 5.12 and 3.65 percent in medium and long term impact of climate change respectively. Yields are projected to decline by a 7.04 percent in medium term and by 5.36 in long term. Total production of groundnut was projected to decrease by an 11.8 percent in the medium term and about 9 percent in the long term.

Generally as per Ricardian type regression based projections, climate change impact is projected to be around 4 to 13 percent in terms of both area and yields of major crops that have high existing cultivation levels. Consequently overall production impacts are decreased up to 22 percent for these crops. Wider fluctuation in area and yield impacts and consequently on production are seen in crops that have low existing base levels. This may be partly due to influence of development factors besides climate change impact. Low value cereals and minor crops that were traditionally cultivated are gradually being replaced by commercial crops like sugarcane, groundnut and food crop like paddy over years. Such trends are also likely to play a role in deciding future area, yields and production levels of crops besides climate change. These are then, the anticipated impact on area, yields and production levels of select crops analyzed, taking into account the adaptations of the farmers at local levels in terms of technological options, crop management, inputs and water control under assumptions of constant input and output prices.

**Multi Goal Linear Programming Model (MGLP) for Optimum Land Use Planning in Study Area of Nagapattinam District in Tamil Nadu**

There are nine pedons in Nagai coastal district of Tamil Nadu. Rice is the major crops in all the pedons followed by prawn culture. A multi objective goal programming model was developed to obtain the optimal cropping patterns which take into account soil productive properties in each pedon. The different objectives studied were (i) maximize rice production (ii) maximizing net return (iii) maximizing gross return (iv) maximizing employment from all the crops.

The study revealed that paddy production in all the nine pedons can be maximized to produce about 21 thousand tonnes with a total area of 11850 acres. From the MGLP model it also indicates that maximum net and gross returns work out to 147 and 324 Million Rs respectively. Maximum employment will be about 3.7 lakh man days from all the crops. It also revealed that labour and water are not constraints for rice production in the study area.

**Table 28. MGLP results: Effect of climate change on rice production**

**(Kharif season)**

| **Parameters** | **Existing (actual)** | **Maximum Possible** | | | |
|---|---|---|---|---|---|
| | | **Existing (maximum)** | **2020 (15% yield decrease)** | **2050 (35% yield decrease)** | **2080 (80% yield decrease)** |
| Paddy Production ( ' 000 tonnes) | 9 | 21 | 18 | 14 | 4 |
| Net Return (Million Rs) | 38 | 147 | 125 | 95 | 29 |
| Gross Return (Million Rs) | 66 | 324 | 275 | 211 | 65 |

Based on HADCM3 model, projected decrease in Kharif season rice yield were about 15, 35 and 80 percent in 2020, 2050 and 2080 respectively. Using these climate change scenarios in MGLP model the maximum paddy production is about 18, 14 and 4 thousand tonnes in 2020, 2050 and 2080 respectively as against the maximum production of 21 thousand tonnes at current levels.

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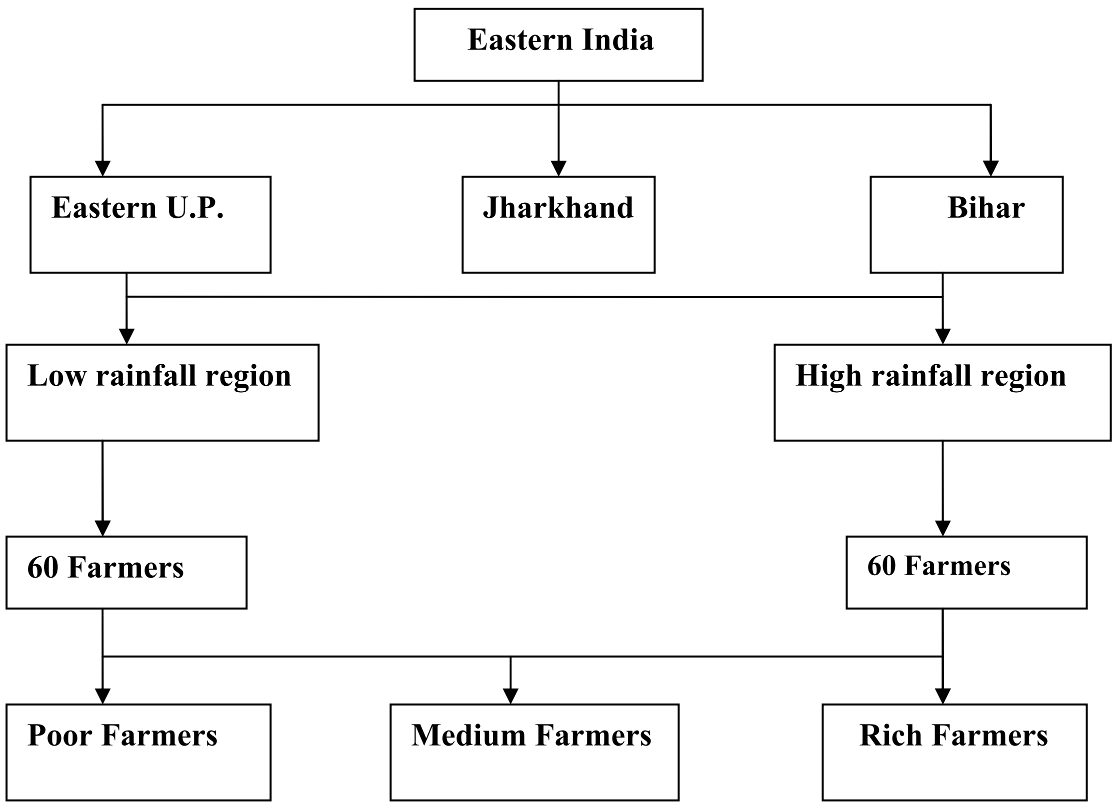
**General features of study area:**

Eastern India comprising eastern U.P., Bihar, Jharkhand, Orissa, W. Bengal & Assam & Chattisgarh is located in the range of coordinates $20^0$ to $30^0$ N & $81^0$-$87^0$E longitudes. Average annual rainfall of Eastern India varies from 700mm. to greater than 2500 mm in Assam. Greater part of region comprising Chattisgarh, Orissa, W. Bengal and Jharkhand receives a rainfall of about of 1250mm/ year. The monsoonal rainfall pattern of eastern India indicated that except in Eastern U.P., parts of Bihar, Jharkhand, W. Bengal and Coastal Orissa, the seasonal rainfall as above 1000mm. Highest rainfall is received as usual in North-East states. The quantum of post monsoon rainfall is low (less than 100 mm) over greater of the region. Few coastal districts in Orissa receive an additional rainfall of about 200-300mm due to occurrence of cyclone. In general, start of growing season in eastern India delays as moves one toward west. (Map of Area shown in fig.)

**Methodology Adapted :**

The study sites in Eastern U.P., Jharkhand and Bihar has been selected zones of High and lowrainfall. Approximately 60 farmers from each zone of three categories i.e., poor farmers, medium farmers and rich farmers have been selected. In all, 180 farmers from Eastern India constituted from three states i.e., Eastern U.P., Bihar and Jharkhand are chosen for detailed study. The Benchmark survey of 180 farmers has been conducted through an appropriate scheduled/Questionnaires to know the impact of various socio-economic parameters from different selected zones in relation to climate change.



**1. Weather/Climate Trend:**

**Past Weather/ Climatic trend:**

- In Eastern U.P. out of 35 yrs., 14 yrs possess the rainfall above the normal, while 6 yrs are drought yrs including light, medium and severe drought, where as in Bihar, this frequency is 12 yrs. of drought and in Jharkhand it is 11 yrs.
- Recurrence frequency of drought in Bihar is once in 3-4 yrs. where as in U.P. it is once in 5-6 years. Orissa have more drought prone area and contains 13 yrs drought and 19yrs as a flood affected. Therefore, the natural scenario including drought, flood, cyclone, Hailstorm etc. in Orissa are much more than expectation.
- District wise annual rainfall in Jharkhand state for the period of 1985 to 2000 reveals that Pakur district of S.P. division contains the highest annual rainfall (1725 mm) and also highest S-W monsoon rainfall (1550 mm). Ranchi is the next highest rainfall region in the state. Hazaribagh of U.C. division falls in lower rainfall region of the state getting 716 mm annual and 575 mm as seasonal rainfall.
- The rainfall pattern of different climatic zones of Eastern U.P. reveals that NEPZ zone possess the highest rainfall (1270 mm annual) among the 3 zones of Eastern U.P. Among the district of this region Gorakhpur, Mahrajganj, possess the highest rainfall. The other two regions like EPZ and VZ have the rainfall at par and falls in medium (1120 mm) and low rainfall (1026mm) category.

- The characteristics of rainfall of Eastern U.P. (i.e. onset and withdrawl of monsoon) from 1976 to 2004 reveals that shift of onset of monsoon from 4 to 6 days toward rainy season consequently length of rainy season also shifts on an average 5 to 6 days early. Average number of rainy days during the year is the highest (63 days) in NEPZ.
- Annual temperature both maximum & minimum in Eastern U.P. did not varied much. Jaunpur district has the highest temperature both maximum & minimum in all the seasons.
- In Jharkhand annual variation of mean temperature has 5$^{th}$ degree polynomial trend which was below the normal (24.3$^0$C) till 1987. Thereafter, temperature increased above the normal but picture for maximum & minimum temperature is peculiar that out of 33 yrs, the minimum temperature during 21 years is below the normal where as 18 yrs is above the normal for maximum temperature in the state.
- In Bihar state also the rising trend of temperature after 1997 is seen and overall trend is 5$^{th}$ degree polynomial. As far as maximum & minimum temperature is concerned, the maximum & minimum temperature exists above the normal in many years (maximum temp= 18 yrs & minimum temp.= 21 years).
- Max. temp. during summer season in Jharkhand increased slowly from 1970 to 2003, while min. temp. during the summer season increased very rapidly. Max. temp during SWM are almost constant while min temp. during the period increased very slowly .During winter season max. temp. increased at faster rate since 1986 onward while min. temp. increased rapidly since 1970.
- During Winter season in Bihar the max. temp. increased very slowly while min. temp. increased sharply during the last decade. Pattern of rainfall was found cyclic of four degree order.
- Trend of max. temp. in Eastern U.P. during summer slowly increased while that of min. temp. was constant during the period of last decade. Trend of rainfall was found cyclic of four degree order.

**Future/ Projected climate Trend:**

- In general the rate of increase of Max. temp. during months in Eastern India will be higher during 2050 to 2080 (2-4$^{o}$C) as compare to 2020 to 2050 (1-2$^{o}$C). Similar observations were recorded for variation of min. temp. too with greater magnitude in both eastern U.P. and Bihar ranging between 3-5$^{o}$C in later part of century as compare to early part (2-3$^{o}$C).
- Future prediction of Tmax. and Tmin scenario on monthly basis of E.U.P., predicts that month of Dec. and Jan. will be hotter as compare to Nov. contrary to normal trend. But in Bihar the increase of Max. temperature during month of Dec. and Jan. was not much distinguished. For min temp. the prediction for both Eastern U.P. and Bihar is similar to increase during month of Dec. and Jan. during 2020 -2080.
- Rainfall Scenario of E.U.P. and Bihar showed much variational trend on monthly basis and observed that in the E.U.P, rainfall will increase during SWM period during 2020, 2050 and 2080 but month of Aug. will face sharp decline of rainfall. In winter season also low rainfall prediction is reported as compare to present normal.
- The two peaks of rainfall during kharif season were reported in Eastern U.P. Primary peak in July and secondary peak in September month. A drastic decrease of rainfall during Aug. was reported in all scenarios. In Bihar, the primary peak of rainfall was much stronger in June as compare to July and secondary peak in Oct. i.e., SWM months (July, August and Sept.) will receive less rainfall as compare to rainfall peaks.
- Trend analysis of temp. (max./min.) of Eastern India shows the increasing trend in both U.P. and Bihar whereas a slight increase in min. temp. in Bihar over E.U.P. was noticed during 2080 only.
- A peculiar picture for rainfall was found that during 2020, the rainfall in Bihar will be lower than Eastern U.P. except 2080.
- Frequency of terminal drought in Eastern India is 70% (1970-2003), but the recent trends of drought shows the frequency of increasing rate of early and intermittent drought.
- GIS mapping of heat and productivity zones of E.U.P have been depicted with future prediction of weather parameters.

**Crop Yield and Climate scenario:**

- Graph between reference year and yield of Major crops of Eastern India (Rice and Wheat) were plotted and trend line i.e., linear/ non linear or single and double trend was decided and trend line equations were obtained. With the help of trend line equation (in case of single trend line), trend of predicted yield and normalized yield deviation (NYD) then after calculation of final NYD were calculated. Regression equation between Kharif rainfall, Max. and Min. Temp. deviation and NYD were developed. Similarly equations between Rabi Rainfall, Max. Temp. and Min temp. deviation and NYD were developed. Slope of regression equation develop shows the sensitivity of crop yield to meteorological parameters i.e., Rainfall and Temp for rice and Wheat crop of Eastern India.
- From NYD analysis for prediction of crop yield on seasonal basis, it has been observed that Max. Temperature may cause the reduction in yield of rice in E.U.P by 1.0% to 1.1% per ha during 2020 to 2080 whereas in case of Bihar, the variation is very least ranging between 0.1% to 0.2% increase in yield per ha. Similarly, Min. Temp. may decrease the yield of Rice in by 1.5 to 1.9% per ha. In E.U.P., whereas in Bihar increase in yield is reported by 1.2 to 1.3% per ha.

- It was observed that S.W. Monsoonal Rainfall will remain the major factor for controlling the yield of rice. By the end 2080, the enhancement of yield in eastern U.P. may increase to the tune of 28 to 29% per/ha and in Bihar increase in yield of rice by 21%/ per ha.
- The role of max. temp. for wheat production in Bihar is significantly observed in coming years to come as compare to E.U.P, the model predicts that wheat yield may **decrease 5-6 %** in Bihar due to max. temp. alone by the end of 2080 whereas this decrement in E.U.P. is reported between 1-1.1%. Similarly the range of sensitiveness of Min. temperature on yield prediction is more in Bihar (2% to 3%) as compare to Eastern U.P. (0.1-0.4%) with respect to average yield.
- Future scenario of rainfall in rabi season in both E.U.P. and Bihar will not affect significantly on yield of wheat crop as compare to Temperature.
- Terminal drought reduced the yield of rice in Eastern U.P. with a margin of 44% as compare to early stage drought i.e., 23%.

**2.Crop Sciences/Agronomy**

- The sensitivity of rainfall for yield of Rice in Eastern U.P. is much larger as compared to Bihar and Jharkhand whereas sensitivity of Max. Temp. of Wheat in Eastern U.P. is very small for yield prediction.
- Yield of rice in the high rainfall area of Eastern U.P. decreases with increase in max. Temp. during the crop season. Quantitatively it was found that $1^0$C rise in max. temp., decreases the yield by 2.5 q/ha. Similarly increase of min. temp. during crop season also reduced the yield of rice with lower magnitude as $1^0$C rise in min. temp. decreased the yield by 2 q/ha only.
- In the medium rainfall region of eastern U.P., Max. temp. is more sensitive for yield reduction as compare to min. Temp. because $1^0$C rise in max. temp. was observed to reduces the yield by 2 q/ha while $1^0$C rise in min temp., reduces the yield only 1q/ha .In low rainfall region trend revealed that rice yield in the area decreased with increase of both max. and min. temp. $1^0$C rise in Max. temp. above $35^0$C reduces the yield about 2 q/ha while $1^0$C rise in min temp. above $26^0$C reduces the yield about 3 q/ha.
- The sensitivity of rainfall for yield of Rice in Eastern U.P. is much larger as compared to Bihar and Jharkhand and sensitivity of Max. Temp. of Wheat in Eastern U.P. is very small for yield prediction.
- Rice and wheat are the prominent cereal crops of the U.P. During 2005-06, the U.P. state produced 235.7 lakh metric tones of wheat from an area of 91.85 lakh. ha with a productivity level of 2.57 tones/ha whereas the crop coverage of Rice during 2006 was 59.25 lakh ha with the total production of 150.6 lakh metric tones at average productivity level of 2.3 tones per ha. (Agril.) Production in U.P. 2005-06). There are wide range of productivity of rice and wheat in Eastern India due to following constraints;
- Prevalence of harsh climate (low/high temp. and moisture stress) in hilly districts of Vindhyan zones.
- Small or marginal and scattered land holdings and women centric Agriculture.
- Low adoption of improved technology and high yielding improved varieties due to poor socio-economic condition of the farmers and poor extension network especially in eastern region.
- Out of total rice cropped area more than 90% area are rainfed rice ecosystems. Due to erratic rainfall and uneven distribution, the frequency of flood in Bihar and Drought in E.U.P. are considerably increasing affecting the crop productivity to the great extent. Rice

farming in eastern India is therefore most vulnerable and risk prone due to complex ecological situations marked by frequent flood and drought.

- Abiotic stress is one of the major constraints for wheat crop due to complex ecological situation during entire crop period. High temperature during reproductive stage of wheat crop is one parameter identified as production constraint.
- There is yield gap between attainable and farm level yields across the ecologies in eastern India, which ranged from 10 to 60 % in rainfed and flood prone.
- Floods prone rice is more vulnerable than other rice grown in rainfed ecosystem, as their yields are low and unstable due to unpredictable droughts, submergence and flash flood.
- The integrated soil and plant nutrient supply system is emerging is the critical requirements for management of long term soil fertility and productivity in the areas.

**Adaptation Strategies:**

- The improved short duration drought resistant varieties of rice viz., NDR-97, NDR-118 and Barani Deep are suggested to farmers for rainfed upland cultivation to sustain the productivity under aberrant weather of Drought and Jalmagna, Chakia 59, Madhukar, Jalnidhi, Jalpriya, Barh Avarodhi are suggested for deep water and low land rice cultivation in the area.
- Hybrid vigour of heat stress in wheat crop and water stress in rice crop need to be exploited as it offers to an increase in yield by 20-25% over best improved varieties under favourable conditions.
- The key components to bridge the yield gap are;
    - Development of location specific varieties and technologies especially for rainfed and flood prone areas.
    - Varieties resistance to heat stress
    - Development of hybrid rice and wheat and new plant types for different ecologies
    - Efficient technological transfer to farmers
    - Easy credit facilities/ policy

- Traditional rice varieties due to their moderate adaptability are still cultivated on larger proportion of rainfed upland areas of eastern U.P. Farmers participatory approach for development of high yielding varieties with improved drought tolerance should be encouraged.
- Integrated crop management needs to be emphasized in future besides developing short duration, drought tolerant varieties responsive to low inputs.
- Floods prone rice is more vulnerable than other rice grown in rainfed ecosystem as their yields are low and unstable due to unpredictable droughts, submergence and flash flood.
- Crop intensification has been one of strategies to step up productivity. Development of short duration varieties like Govind, Saket 4 and NDR-97 etc. helped to fit into diverse rice based cropping system of U.P.
- Rice cultivation in upland rainfed involves a lot of risk. Plant, soil and water relations reducing potential productivity are a critical constraint accounting for 30% of yield losses in Eastern India.
- Rice and wheat both are dominant component of food grown in U.P. Rice –Wheat cropping system in the Indo-gangetic plains are showing sign of “Fatigue” due to continuous supply of this highly nutrient and water exhaustive cereal- cereal system for last 3 decades uninterruptedly without corrective ameliorative measures.

- The integrated plant nutrient supply system is emerging as the most logical concept for managing long term soil fertility and productivity.

**3.Economics**

- Average temp. of kharif of Eastern U.P. is beneficial evalution of land value while that of rabi are harmful. From Ricardian model it was found that 1% increase in kharif rainfall decreased 39.2% of land value remaining other parameters at constant and normal value. In the same way if 1% decreases in rabi rain combined with kharif rain, the land value decreased drastically.
- Precipitation is relatively more important than temperature in the Bihar state in respect of farm value and found that 1% increase in Kharif rainfall alone will add 32.5% of the land value provided other parameters are constant and at normal value. But 1% increase in rabi rain combined with kharif rain, the land value decreased by margin of 3%.
- Kharif temp. (Max and Min.) in Jharkhand state are more harmful than rabi temp. in respect of farm value.Rain is more sensitive and effective than the temperature to assess the land value . Rain is +vely correlated while later is –vely.
- Using Ricardian approach the regression obtained for land values from climatic and socio-economic variables to estimate the best value function across different sites viz., Eastern U.P., Bihar and Jharkhand and found that;

**In Bihar:**

- Precipitation is relatively more important than temperature in respect of farm value.
- 1% increase in Kharif rainfall alone will add 3.25% of the land value provided other parameters are constant and at normal value. But 1% increase in rabi rain combined with kharif rain, the land value decreased by margin of 3%.
- Kharif Minimum temp. are harmful while kharif max. Temp. are beneficial but in the rabi season both max & min. temp. are beneficial for land value and farm revenue .

**In Jharkhand:**

- Rain is more sensitive and effective than the temperature to assess the land value. Rain is +vely correlated while later is –vely.
- Kharif rain and rabi max. temperature are harmful for evaluation of land value where as rabi rain, kharif max and min. temperature and rabi min. temperature are beneficial.
- Kharif temp. (max and Min.) are more harmful than rabi temp. in respect of farm value.
- 1% increase in rabi rainfall, will add the largest proportion on land value provided other parameters are constant and at normal value. Also the increase in kharif rain combined with rabi rain, the land value increased drastically.

**In Eastern U.P.**

- Temperature is relatively more important and sensitive than precipitation in the area in respect of assessment of land value and farm revenue.
- High rainfall during kharif and rabi season, decreases the land value. But increase in kharif max temp are harmful in the area for land value .where as rabi maximum temperature and kharif and rabi minimum temperature are beneficial.
- Average temp. of kharif is beneficial while that of rabi are harmful.
- It is found that 1% increase in kharif rainfall in low land decreased 3.9% of land value remaining other parameters are constant at normal value. In the same way if 1% decrease in rabi rain combined with kharif rain, the land value decreased drastically.

**Climate Impact on Land Value of Poor rural masses:**

- On the survey and Questionnaire basis of Sonebhadra district which belongs to the Vindhyan Zone of Eastern U.P. belonging 45% population to SC/ST with small/ marginal farmers having the average land size 0.4 ha, land value was evaluated with climatic variables for poor masses and found that;
- Kharif rain is much harmful in respect of land value for poor farmers as compare to large farmers in the area.
- Both Rabi and Kharif Tmax. is also harmful for land value to both small and large farmers.
- 1% increase in Kharif rain decreases the land value more rapidly to small farmers as compare to large farmers.
- Average number of the female members engaged in Dairying occupation was significantly higher in comparison to male members (2.48±0.16 vs 1.58±0.05) in Eastern U.P., Bihar and Jharkhand during 2004-05. In most of the cases animal houses are part of farmers residence. Animals were housed both in the *Kuccha* (81.50%, 76.30% and 82.61%) & *Pucca* type (14.8%, 25.8% & 8.2%) houses respectively in the Eastern U.P., Bihar and Jharkhand state. Open houses were preferred by 82.3%, 69.4% and 83.7% respectively in these three states by the farmers.

**4.Climate and Live stock**

**Live-stock statistics (Production and Health):**

- In Jharkhand state during 1982-2003, among the major livestock population, the percent increase population of pigs were maximum i.e. 164% followed by buffalo & goat 33% and 27% respectively.
- Density of livestock & poultry in Jharkhand state during 1972 to 2003 increased substantially i.e. Livestock increase was 39% & that of poultry increase was 92% during 32 years. Hence poultry farming was more popularized in the state as compare to other livestock farming.
- In undivided Bihar, the increase in Egg production during 1976-1977 to 1983-84 was recorded highest i.e. 68% among major Livestock products followed by meat 42%, wool and milk 23% only.
- During 1995-2002 among the major diseases of Livestock, 78% FMD (foot mouth diseases) was reported in the state during winter season. In rainy season, highest (93%) of Hemorrhagic sephcemia (HS) disease was reported in state.
- In Eastern U.P. the livestock population in high rainfall area (Gorakhpur) and undulated low rainfall area of Mirzapur division is very interesting that in Gorakhpur during 1988-2003 percentage increase of Buffalo is 37% followed by Goat 21%. While that in Mirzapur, the population of all livestocks increased unexpectedly. Pig increase was 166% followed by Buffalo and Sheep 78% and 77% respectively Goat percent was also increased by 56% i.e. rural masses more depend on livestock may be due to poor socio-economic status, undulated topography, erratic rainfall and drought prone region of the eastern U.P.
- Livestock production in both the high & low rainfall region of eastern U.P. (i.e. Gorakhpur & Mirzapur) during 2000-2001 to 2003-3004 is of slow rate. 4% per year increase in milk, 8% in Egg, 7% & 5% increase per year in meat & wool were recorded in Gorakhpur division while that of in Mirzapur only 20% increase in milk production were recorded per year with maximum 45% increase in meat production. Wool production in the area was declined drastically.

- Seasonal variation in milk production in both Gorakhpur & Mirzapur region shows that during winter season the production is highest followed by Rainy & summer season.
- Meat production in eastern U.P. during 2000-01 to 2003-04 increased within the range of 11 to 31 with max. in Pig meat followed by Buffalo meat production.
- Relative humidity and Photoperiod found to have hampered the Sheep rearing in Jharkhand state as increased humidity retards wool growth.
- Lactating animals present in Eastern U.P., Bihar and Jharkhand, in 2004-05 is declining by around 40.90%, 35.16% and 25.35% respectively as compared to that in 1981-82. Scanty availability of round the year fodder production due to undulant rainfall patterns has made the specific changes in the animal rearing in these three states.
- Almost all farmers fed green fodders (*Barseem, Bajra, Maize and Jowar*) as well as chaffed Dry fodder (*Wheat straw, Paddy straw & kadbi of Bajra, Maize & Jowar*) to their animals. Concentrate mixture was provided to animal mostly at time of milking (98.2%, 98.6% and 97.6%) respectively, in these three states. In Bihar the concentrate feeding to the animals is found out to be maximum whereas in Jharkhand state grazing pastures available are maximum probably this is due to high rainfall pattern in Jharkhand state during last 15 yrs. The scarcity fodder availability was also maximum in Jharkhand state. The majority of the farmers of eastern U.P. prefers stall feeding to their animals as compared to the farmers of Bihar & Jharkhand states.
- In all three states the animal diseases like FMD, BQ, H.S., Pneumonia, Diarrhoea, Bloat, Mastitis and Protozoal diseases like Theileriosis, Surra and other Parasitic diseases were prevalent in the area. Therefore Weather Based Disease Forecast (WBDF) is to be provided at regional levels to sustain various diseases to increase reproductive efficiency in livestock species.
- As per the livestock census of 2003 the population of sheep in Jharkhand state has declined by about 31% as compared to that of in 1981-82. Relative humidity and Photoperiod may have hampered the Sheep rearing in Jharkhand state as increased humidity retards wool growth. Therefore, rectified methods to be evolved for maintaining and breeding of sheep production as a lucrative business as per the present climate change in Eastern India. Also the alternative sources of fodder crops such as *subabool, peepal* leaves and *ber* leaves for sustainable meat production for marginal farmers is to be suggested.
- Density of livestock & poultry in Jharkhand state during 1972 to 2003 increased substantially i.e. Livestock increase was 39% & that of poultry increase was 92% during 32 years. Hence poultry farming was more popularized in the state as compare to other livestock farming.
- In undivided Bihar, the increase in Egg production during 1976-1977 to 1983-84 was recorded highest i.e. 68% among major Livestock products followed by meat 42%, wool and milk 23% only.
- During 1995-2002 among the major diseases of Livestock, 78% FMD (foot mouth diseases) was reported in the state during winter season. In rainy season, highest (93%) of Hemorrhagic sephcemia (HS) disease was reported in state.
- In Eastern U.P. the livestock population in high rainfall area (Gorakhpur) and undulated low rainfall area of Mirzapur division in very interesting that in Gorakhpur during 1988-2003 percentage increase of Buffalo is 37% followed by Goat 21%. Sheep & Pig percentage tremendously from 1988 to 2003. While that in Mirzapur, the population of all livestocks increased unexpectedly. Pig increase was 166% followed by Buffalo and Sheep 78% and 77% respectively Goat percent was also increased by 56% i.e. rural masses more

depend on livestock may be due to erratic rainfall and drought prone region of the eastern U.P.

- The scenario of total population of livestock in eastern U.P. during 1988 to 2003 as given in table is encouraging as many fold increase in the population of all major livestocks were reported during 1988-2003 with maximum 7 fold increase in Pig.
- Livestock production in both the high & low rainfall region of eastern U.P. (i.e. Gorakhpur & Mirzapur) during 2000-2001 to 2003-3004 is of slow rate. 4% per year increase in milk, 8% in Egg, 7% & 5% increase per year in meat & wool were recorded in Gorakhpur division while that of in Mirzapur only 20% increase in milk production were recorded per year with maximum 45% increase in meat production. Wool production in the area was declined drastically.
- Seasonal variation in milk production in both Gorakhpur & Mirzapur region shows that during winter season the production is highest followed by Rainy & summer season.
- Meat production in eastern U.P. during 2000-01 to 2003-04 increased within the range of 11 to 31 with max. in Pig meat followed by Buffalo meat production.
- Animal's productivity was found affected by climatic environment both directly and indirectly. Indirectly. The temperature, humidity, air movement, solar radiation, and rainfall are major climatic parameters affecting the nutritional plan of animals through the amount of crops and pastures.

**Effect on milk Production:**

The milk yield of all mammalian species undergoes seasonal variations. In cattle, the yield was relatively unaffected within the temperature range of 5 to $21^0$C. At temperature lower than $5^0$C as well as from $21\text{-}27^0$C, the yield decreases slowly; whereas above $270^C$ the decline is much more marked. It has been estimated that milk production decreased approximately by 1 kg. for each degree ($^0$C) rise in rectal temperature.

The percentage of milk fat reduced between the environmental temperatures $21\text{-}27^0$C, but beyond $27^0$C the percentage increased,

The response of wool growth to the environment varied according to the breed of sheep, physical condition of the animals, plan of nutrition, sex, shearing and seasonal and diurnal variation in environmental temperature and photoperiod. Maximum growth wool production occured in summer and minimum in winter. This annual rhythm is further affected by the stage of reproductive cycle e.g. the demands of Pregnancy further reduces wool growth in winter and lactation delays the rise both the thyroid and adrenal gland activity.

**Effect on egg production:**

- Within the range of environmental temperature of $9^0$C to $29^0$C egg production in the domestic fowl was not reduced.
- Thermal stress, especially sharp changes in temperature, adversely affected both egg weight and shell quality. A 24- hours exposure to $38^0$C resulted in a sudden, temporary drop in egg production of some strains but not in others.
- The limits of temperature tolerance for a given animal are not fixed. Exposure to a near-lethal temperature often leads to a certain degree of adaptation. Frequently the range of thermal tolerance is different for the same species in summer and in winter. A winter animal have often tolerances and even are active at a temperature so low that it is lethal to a summer animal; conversely, the winter animal is less tolerant to high temperature than a summer animal. Such changes in the temperature tolerance with climatic changes are called acclimatization.

**Impact of climatic variation on animal health and productivity:**

- Solar radiation affected the skin of animals causing sun burns, skin cancer, photosensitive disorders and increased the heat load on animals. This also affected the growth, production and reproduction. Since the skin colour, length, density and condition of hair determines the amount of heat absorbed by body from solar radiation hence, Buffaloes were more susceptible to solar radiation. Standing animals absorb less solar radiation than those laying those down.
- Rise in environmental temperature changes the body temperature resulting in shift in the blood perfusion in the hypothalamic regions.
- Changes in the body temperature alter the metabolic activity of the animal.
- At temperature below the critical temperature, caloric requirements for body maintenance are higher due to increased heat loss. Those more tolerant to heat stress generally have greater ability to perspire and more skin surface area per unit weight.
- Heat stress is multifaceted adaptive response phenomenon that occurs during high environmental temperature. During such periods capacity of an animal for heat dissipation is exceeded by heat production. First reactions of animals to elevated temperatures beyond the thermoneutral zone are a decrease in feed intake. The extent of this depression is proportional to the thermal stress.
- High environmental temperature depresses body activities to protect from overheating. Overheating create physiological stress which affect reproduction and production by promoting an unfavourable endocrine balance, by altering metabolism or by reducing feed intake.

**Adaptations:**

- Usually, animals graze and eat during day time in summer and tend to eat more during the night and thus can rearrange the major part of the thermogenic fermentative activity to take place during the cooler part of the day facilitating thermolysis to the cooler surroundings. This adaptive mechanism is found to cope up with heat stress during the critical limit for a short duration in daytime. If the thermal stress is of longer duration during the day in extreme summer, or when more intense heat as a result of high environmental temperature during drought sustained for many weeks, there is significant fall in absolute feed intake and less or no compensation during night shift is observed because day to night shift in feed intake is of transit nature. As the thermal stress withdraws itself during the night, there is retrieval in feed consumption.
- <u>Thermal Index (THI)</u>
- THI= 0.72 (dry bulb temperature $^0$C + wet bulb temperature $^0$C) + 40.6
  THI below 72 = No stress on animal
  = Mild stress
  = Medium stress
  = Severe stress

Above 98 = Heat stroke/ Death condition.

- The first and more easily recognizable adaptive behaviour in cattle is the movement for seeking shade following a decrease in food intake as well as desire for it, particularly when ambient heat greatly exceed than body heat.

- A 25% fall in milk production occurs as a result of heat stress in dairy cattle. Milk yield along with solids in milk significantly decreased during thermal stress.

**Adaptation management during climatic change:**

**a. Summer management**
Thatch and mud are excellent roof materials to create better microenvironment around the animal, which is turn lead to improve the growth rate and physiological comfort of the young buffalo calves under hot dry conditions.

**b. Winter management**
Slightly higher dry matter and energy rich ration may enable animals to cope up with cold during extreme winter climate including proper indoor sheltering during night and sunlight in the open.

**c. Nutritional management**
Higher heat increment because of poor quality highly fibrous feeds and higher BMR in high producing animals may be reduced by feeding protected fat and limiting amino acids in their diet.

Provision of clean drinking water and fluid balance is most critical aspect of therapeutic nutrition, to maintain constant body water volume and electrolyte balance during heat stress.

Heat stressed animals are subjected to negative nitrogen balance due to reduced ration consumption and to cope up this situation increasing protein percentage in diet of heat stressed animals would be beneficial.

**Seasonal variation on biological responses and productivity of Livestock:**

The data on the feed consumption has been shown Table –1. The dry matter consumption in kg per 100kg body weight was 3.63± 0.03, 3.09±0.02, 2.83±0.03, 2.69±0.11 and 3.12±0.04 in winter, spring, summer, rainy and autumn seasons respectively. There were significant differences in dry matter intake per 100 kg body weight ($P<0.01$) between seasons.

A reduced feed intake by Sahiwal and Brown swise- Sahiwal bull calves at the peak of summer without any accompanying increase in digestibility, suggest that the reduced feed utilization was in impairment of digestibility rather than an adaptive adjustment. Significantly higher dry matter digestibility was observed in winter than in other seasons of the year. There was a sharp decline of feed consumption of buffaloes.

It was revealed that the effect of temperature on digestion in buffaloes during summer when the environmental temperature reached 40-45$^0$C.lost digestive activity hence affecting the animal health.

- Voluntary food intake and nitrogen intake in buffalo falls with rising environmental temperature exceeding 32$^o$C and the beginning of the fall coincides with the beginning of the rise in body temperature.
- The present findings also show that dietary systems at higher humidity under tropical conditions are better for animal's health and production.
- Rectal temperature varies with season during milking stage, the differences between morning and evening rectal temperature were significant ($P<0.01$) in all the seasons. During morning hours the rectal temperature was least (37.8$^0$C) in winter season when compared with (38.5$^0$C) summer months. The rectal temperature was significantly related to the ambient temperature and relative humidity. There was a significant linear increase ($P<0.01$) in rectal temperature upto (38.5$^0$C) in summer season.
- The data on milk yield and its composition has been analyzed and showed that significant difference ($P<0.01$) in milk yield and FCM yield existed in different seasons. Milk yield was reduced in summer season of the year.

**ANNEXURE 7: Papers published:**

**Indian Agricultural Research Institute**

1. **Aggarwal, P.K., Banerjee, B., Daryaei, M.G., Bhatia, A., Bala, A., Rani, S., Chander, S., Pathak, H., and Kalra,N., (2006).** InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. II. Model performance. *Agricultural Systems*, 89: 47-67.
2. **Arti Bhatia, P.K. Aggarwal and H. Pathak (2007)** Simulating greenhouse gas emission from Indian rice fields using the InfoCrop model. Accepted in *IRRN*.
3. **Manjaiah, K.M., Utpal Sen and Praven Sachdeva 2006**. Effect of tillage and integrated nutrient management on carbon storage and mineralization in Typic Haplustept under Rice-Wheat system. 2nd International Rice conference, New Delhi from 9-13 October, 2006.
4. **Nagarajan, S., Anjali Anand, Joshi, D.K., Verma, A.P.S. and H.B. Choudhary (2006)**. Evaluation of diverse wheat geneotypes for high temperature and drought tolerance using biophysical and meteorological indices pp. 33-42, In: Wheat for Tropical Areas (Eds. K.A. Nayeem, M. Sivasamy & S. Nagarajan), Laser park Publishers, Coimbatore, India.
5. **Banerjee, B., Nagarajan, S., Prasead,H., Aggarwal, P.K. (2006)**. Impact of temperature on pollen germination and spiklet sterility in rice, Abstract No. 5283, 2nd International Rice Congress, October 9-13, 2006, New Delhi
6. **Anjali Anand and Nagarajan, S. (2006).** Response of different growth stages to elevated temperature in aromatic and non-aromatic rice cultivars, Abstract No. 5324, 2nd International Rice Congress, October 9-13, 2006, New Delhi
7. **Anjali Aannad, Nagarajan, S and Pathak, P.C. (2007)**. Effect of high temperature on hydrogen peroxide scavenging enzymes during reproductive phase in aromatic rice cultivars. Indian Journal of Plant Physiology, 11, 427-431.
8. **Nagarajan, S., Anjali Anand and Hariprasad, A.S. (2006)**. Impact of growing environment on grain quality traits of rice and their relationship with temperature and radiation in New Delhi, India, Abstract No. 5325, 2nd International Rice Congress, October 9-13, 2006, New Delhi
9. **Hari Prasad, A.S., Tomar, A.K. and Omvir Singh (2006)**. Effect fof growing environment on phenology, growth and yiel;d parameters of rice varieties, Abstract No. 1681, 2nd International Rice Congress, October 9-13, 2006, New Delhi
10. **Nagarajan, S., Tripati, S., Singh, G.P. and Choudhary. H.B. (2006).** Effect of environment and genotypes on quality of wheat (*T. aesivum* L) Abstract 28p, International Conference on Post-harvest technology and Value addition in cereals, pulses and oil seeds, November 27-30, C.S. Azad University of Agriculture & Technology, Kanpur. U.P.

**Jawahar Lal Nehru Krishi Vishwavidyalaya, Jabalpur**

Papers presented in International and National Seminars

1 **Upadhyaya, S. D. and Sharma, S.B. (2007).** Variability in photosynthetic characteristics of healing herbs grown outside and under agroforestry systems. Abstracts; Vol -1- International Conference on Sustainable Agriculture for food, Bio-energy and Livelihood Security Organized by JNKVV, Jabalpur (M.P.), pp 179-180.

2 **Jain, S., Sharma, S.B. and Upadhyaya, S.D. (2007).** Temperature variation responses to morpho-physiological characteristics of Medicinally Importatn herbs viz. Isabgol (*Plantato ovata*) and Chandrasur (*Lapidium Sativum*) Abstracts; Vol –II- International Conference on Sustainable Agriculture for food, Bio-energy and Livelihood Security Organized by JNKVV, Jabalpur (M.P.), pp 461.

**Indian Institute of Horticultural Research, BANGALORE**

1 **Sridhar, V and Jhansi Rani B**. "Effect of weather factors on population fluctuation of chilli thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) on rose. Paper presented in National seminar on Impact, Adaptation and Vulnerability of Indian Agriculture to Climatic change held at IIHR, Bangalore on 9.12.2005 Pp.89.

2 **Sridhar, V. Krishna Kumar, N.K. and. Jhansi Rani B.** Climate change and its impact on insect pests. Paper presented in National seminar on Impact, Adaptation and Vulnerability of Indian Agriculture to Climatic change held at IIHR, Bangalore on 9.12.2005 Pp.90.

3 **N.K Srinivasa Rao, R.M. Bhatt, M.K. Usha Kumari and L.R.Keerti (2005).** Adaptation Strategies of Onion and tomato to moisture stress. National Seminar on "Impact, Adaptation and Vulnerability of Horticultural Crops to Climatic Change" held at IIHR, Bangalore on 9 December 2005

4 **N.K Srinivasa Rao, N.K.Krishna Kumar, R.Venugopalan, CM. Kalleswara Swamy, M.K. Usha Kumari and L.R.Keerti (2005).** Interaction effect of water stress and thrips infestation at different growth stages. National Seminar on "Impact, Adaptation and Vulnerability of Horticultural Crops to Climatic Change" held at IIHR, Bangalore on 9 December 2005.

**University of Horticulture and Forestry – Solan**

**1** **Verma K S, Bhardwaj D R, Chand Krishan, Kumar Sanjeev, Goswami Sandhya & Thakur N S.** Regional Climatic trends and climate change mitigation Potential of agroforestry systems in Himachal Pradesh. *Journal of Tree Sciences* (Submitted, 2006).

**2** **Verma K S, Bhardwaj D R, Pant K S, Chand Krishan, Kumar Naresh & Thakur N S. (2005).** Status Paper: General Scenario and Climate Change Mitigation Potential of Agroforestry. Department of Silviculture & Agroforestry, Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan, H.P.

**3** **Bhardwaj D R & Verma K S. (2006)**. Effect of haze formation on climate change and vulnerability of agroforestry tree species in subtropical and temperate parts of Indian continent. Paper presented in National Agroforestry Worshop (15-17 December, 2006) held at NRC For Agroforestry Jhansi, U.P., India

4 **Verma K S, Bhardwaj D R, Chand Krishan, Kumar Sanjeev, Goswami Sandhya & Thakur N S.** Carbon inventory and $CO_2$ mitigation potential of agroforestry systems in different climate types of Himachal Pradesh Himalayas. *Indian Journal of Agroforestry* (Submitted, 2007).

**<u>National Dairy Research Institute – Karnal</u>**

1 **R.C.Upadhyay, S.V.Singh, Ashutosh, Ashok Kumar, Asvene K. Sharma, Sandeep K. Gupta (2006)** Biotechnological interventions under Climate Change scenario for improving animal productivity. National Biotechnology Conference-2006 Current Trends & Future Perspectives, September 2 - 3, 2006 at I.I.T, Roorkee. (Invited presentation)

2 **R.C.Upadhyay and Ashutosh (2006).** Livestock sectors clean water requirements in India. In, National seminar on "Technological Options for Improving Water Productivity in Agriculture" 15 - 17 November, 2006. Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) Jabalpur, Madhya Pradesh, India

3 **R.C. Upadhyay, Ashok Kumar, Ashutosh, S.V. Singh and Avtar Singh (2007)**. Impact of climate change on milk production of crossbred cows. 4 th Congress of Federation of Indian Physiological Societies (FIPS), January 11-13, 2007, DIPAS, DRDO, Delhi (Invited presentation).

4 **S.V. Singh, R.C. Upadhyay Ashutosh and Sanjay Kumar (2007).** Impact of temperature rise on physiological functions and thermal balance in lactating Karan Fries and Sahiwal cows. 4th Congress of Federation of Indian Physiological Societies (FIPS), January 11-13, 2007, DIPAS, DRDO, Delhi.

5 **Vijay Kumar and R.C. Upadhyay (2007)**. Impact of high temperature and humidity on core and skin surface temperatures of lactating Zebu and crossbred cows. 4th Congress of Federation of Indian Physiological Societies (FIPS), January 11-13, 2007, DIPAS, DRDO, Delhi.

6 **S.V. Singh and R.C. Upadhyay (2005).** Environmental Stress on Livestock in Arid and Semi Arid Regions. In: "*Livestock Feeding Strategies for Dry Regions*" published by International Book Distributing Co. Lucknow. Pages: 303-319.

*7* **Sanjay Kumar, S.V. Singh and R.C. Upadhyay (2006).** Residue: Risk and Concern. In: "*Agroforestry and Livestock Production*" published by International Book Distributing Co. Lucknow. (Under printing).

*8* **R.C. Upadhyay, S.V. Singh (2006)**. Impact of Temperature Humidity Index on milk production of crossbred cows. In, International Interdisciplinary Conference on Sustainable Technologies for Environment Protection " Probing the Boundries" Coimbatore Institute of Technology, Coimbatore in collaboration with College of Engineering, University of Toledo, Ohio, USA, January7-9, 2006

*9* **S.V. Singh, R.C. Upadhyay Ashutosh and S.S.Kundu (2006)**. Trends in Tmax and Tmin and its influence on buffalo productivity in Bundel khand region. In, In, International Interdisciplinary Conference on Sustainable Technologies for Environment Protection " Probing the Boundries" Coimbatore Institute of Technology, Coimbatore in collaboration withCollege of Engineering, University of Toledo, Ohio, USA, January7-9, 2006

*10* **R.C. Upadhyay, S.V. Singh, Ashutosh and Sanjay Kumar (2005).** Tapkaram – Aadarta Suchkank Evam Pashu Utpadakta. Poster presentation- Hindi articles, Hindi Week Celebrations held on September 14, 2005 at NDRI, Karnal.

**Narendra Dev University of Agriculture and Technology –Faizabad**

**(a)Published:**

1 **Tripathi, P., Singh A.K., Kumar, A, and Chaturvedi A. (2005).** Heat-use efficiency of wheat (Triticum aestivum) genotypes under different crop growing environments. The Indian J. Agric. Sci. 74(i): 6-8

2 **Tripathi, P., Singh, A.K., and Mishra, S.R., (2005).** Study of temperature modification by rice crop and its impact under rice-wheat cropping system.Internat. J. Agric. Sci. vol.1(1) p:11-15.

3 **Tripathi P. (2005).** Impact and Vulnerability of Climate change –Drought and Floods. In Proceeding of Lectures delivered in training organized Centre of Advanced Studies on Crop Physiology, N.D.U.A&T, Kumarganj Nov. 5, pp 35-44.

4 **Tripathi, P., Sharma, R.B., Chaturvedi, A, Singh, A.K. and Mishra. S.R.(2006)** Recurrence probability, intensity pattern and Agro-climatic analysis of drought in Eastern U.P. Internat. J. Agric. Sci. vol.2 (1)p 13-18.

5 **Singh, D.K., Tripathi, P., and Singh, A.K. (2006).** Absorbed photosynthetically active radiation of different moisture regimes in aonla and aonla+guava cropping system. Jr of Agrometeorology, Anand Vol 8(1): 48-53.

6 **Kumar, A., Tripathi, P., and Singh, A.K.,(2006).**Effect of dry spell on growth, development and yield of rice (Oryza sativa-L.) Ind. J. Agric. Sci., 76(1): 47-49, New Delhi (Jan 2006)

**7** **Tripathi, P. Chaturvedi, A and Singh, A.K. (2007).** Agro-climatic analysis of rice productivity in rainfed areas of Eastern U.P. during SW Monsoon period. Int. Jr. Agric. Res. Published vol. 5 (2) p 24-29.

**(b) Papers Communicated:**

8 **Singh, A..K., and Tripathi, P., (2005).** Response of plant population and moisture regimes on soil moisture extraction pattern, consumptive use and water use efficiency of winter maize. Jr. of Res. BAU., Ranchi.

9 **Shabd Adhar; Kaushik, S. Baxla, A.K. Tripathi, P and Singh K. K. (2006).** Validation of CERES Rice V3.5 under the climate of Awadh region of Uttar Pradesh.Mausam (2006)

10 **Kumar, S. Tripathi, P , Mishra, S.R. and Mishra,J.P.(2007**).Study of economic impact of medium range weather forecast on rice and wheat production in eastern U.P. Jr of Agrometeorology, Anand

11 **Kumar, S. Tripathi, P and Mishra, S.R (2007).** Study of seasonal verification of scores of medium range weather forecast in eastern U.P. Jr of Agrometeorology, Anand.

12 **Kumar, S. Tripathi, P, Mishra, S.R and Chaturevdi, A. (2007**). Usability and success probability of medium range weather forecast in eastern U.P. Int. Jr. stat. and Agric. Sci.

13 **Singh R.P., Singh P.K. and Singh A.K. (2007).** Comparative performance of green manuring of Dhaincha (Sesbania aculeata) and Sunhemp (Crotalaria Juncea) on physio-chemical properties of soil, N uptake and productivity of rice Oryza.

**(c) Abstract (National/ International symposium):**

14 **Tripathi, P., Chaturvedi, A., Srivastava, S.A. and Singh A.K. (2006). Crop Modelling and role of GIS in Agro-Advisories services**, In abstract proceeding of National seminar on Agrometeorological services for crop and location specific Advisories held on dated 21-22 June, 06 at IMD., Pune .

15 **Tripathi, P. and Chaturvedi, A. (2006).** Attended an International Workshop on Agrometerological risk Management: Challenges and Opportunities on 25-27 Oct, 2006 at Vigyan Bhawan, New Delhi

**16 Tripathi, P. and Chaturvedi, A. (2007).** Temporal variation of rainfall intensity, rainfall partitioning and its correlation with meteorological elements of Eastern India. Published in Abstract procc. of International symposium on "**Study of rainfall rate and radio wave propagation**" held Sona college of Technology, Tamilnadu on 29-30 Jan., 2007.

17 **Tripathi, P., Chaturvedi, A., Srivastava, S.A. and Singh A.K. (2006).** Crop Modelling and role of GIS in Agro-Advisories services, National seminar on Agrometeorological services for crop and location specific Advisories to be held on dated 21-22 June, 06 at IMD., Pune